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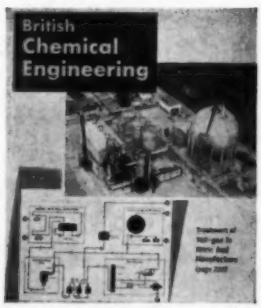

The front cover shows an aerial view of the tail gas unit at Fisons ammonium nitrate plant at Stanford-le-Hope, Essex. Below this unit, engineered by C.J.B., is shown a simplified flow diagram of the main plant.

Classified Advertisements, after page 762

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QUELQUES CONSIDERATIONS DE LA CORRELATION DES LITS FLUIDISES A PHASE DENSE—2ème PARTIE

par M. Leva

L'auteur examine d'abord l'échange de chaleur entre le lit et les surfaces extérieures, puis il étudie l'échange de chaleur entre le lit et les surfaces intérieures. Il parle brièvement de l'échange de chaleur entre les particules et le gaz fluidisant, ainsi que du transfert massif dans les gaz et les systèmes liquides fluidisés.

B.C.E., 5, 11, 773. U.D.C. No. 66.022.28.

LA THEORIE ET LA PRATIQUE DE LA COMMINUTION — 2ème partie

par D. Kelleher

On considère la validité d'un certain nombre de lois, dont celles de Kick, de Rittinger et de Bond, en particulier la troisième loi de ce dernier, et la déviation exponentielle de la loi de Kick présentée par Holmes. On examine des méthodes permettant d'utiliser la théorie pour le choix de l'équipement, la détermination des besoins en énergie et l'exploitation de cet équipement avec une dépense minimum d'énergie.

B.C.E., 5, 11, 784. U.D.C. No. 66.011.

CONSTRUCTION D'EQUIPEMENTS POUR UNE RENTABILITE MAXIMUM

par J. J. Taborek, Phillips Petroleum Company, Bartlesville, Oklahoma

La relation entre les bénéfices et les dépenses est considérée comme la base des travaux destinés à construire l'équipement de façon qu'il soit aussi rentable que possible. L'auteur examine l'ensemble des éléments de production à inclure dans les calculs d' " optimisation ". Il passe en revue, brièvement, les méthodes permettant de calculer les dessins optimum : *a*) méthode analytique classique ; *b*) méthode des multiplicateurs indéterminés ; *c*) méthode de la courbe ascendante maximum ; et *d*) méthode de l'étude réitérée de cas d'espèce. Il compare les mérites et possibilités de ces diverses méthodes, en ce qui concerne, en particulier, leur adaptation éventuelle aux calculatrices numériques. Il esquisse les possibilités d'avenir dans ce domaine.

B.C.E., 5, 11, 789. U.D.C. No. 66.047.32:66 074.66

LA REDUCTION CATALYTIQUE DES GAZ D'ECHAPPEMENT DES INSTALLATIONS D'ACIDE NITRIQUE

par W. Fletcher

On passe en revue les méthodes modernes utilisées pour éliminer le peroxyde d'azote des gaz d'échappement par combustion catalytique au méthane ou à l'hydrogène. On considère l'aspect économique de la récupération d'énergie dans les installations de production d'acide nitrique, ainsi que le prix et la construction de l'équipement de combustion.

B.C.E., 5, 11, 791. U.D.C. No. 66.047.791.

LE SECHAGE PAR ATOMISATION DES PIGMENTS EN BOUE

par Ing. G. Kiraly

En utilisant une méthode simplifiée pour l'étude de la mécanique de la formation des gouttes aux ajutages à turbulence et fluide unique, et du transfert de chaleur entre le moyen de chauffage et les gouttelettes, l'auteur a été amené à construire un sécheur-atomiseur expérimental dont il décrit la performance en détail. Les résultats obtenus permettent de rassembler des données qui serviront à la construction d'un appareil commercial.

B.C.E., 5, 11, 795. U.D.C. No. 542.63:66.061.

DIFFUSION DANS LES LIQUIDES DILUES : UNE NOUVELLE CORRELATION

par S. H. Ibrahim et N. R. Kuloor

Les auteurs ont mis au point une méthode simple pour évaluer les coefficients de diffusion des liquides ; elle est basée sur la prémisse que le coefficient de diffusion est une propriété moléculaire. La corrélation s'obtient avec l'aide d'un nouveau nombre Schmidt sans dimension. Les auteurs donnent une explication du facteur de solution qui apparaît dans ce genre de corrélation lorsqu'on applique les données relatives à l'eau à d'autres solvants. La nouvelle corrélation est vraie avec une marge d'erreur moyenne de ± 10%.

Kurzreferate

B.C.E., 5, 11, 766. U.D.C. No. 66.096.5.

BEZIEHUNGEN ÜBER DICHTE WIRBELBETTEN—TEIL II

von M. Leva

Einer Besprechung des Wärmeaustausches zwischen dem Bett und den äusseren Oberflächen folgt eine Untersuchung des Wärmeaustausches zwischen dem Bett und den inneren Oberflächen. Der Artikel bespricht auch kurz den Wärmeaustausch zwischen Partikeln und Wirbelgas und die Massenübertragung in Gasen und Flüssigkeitssystemen.

B.C.E., 5, 11, 773. U.D.C. No. 66.022.28.

VERMAHLUNGSTHEORIE UND -PRAXIS — TEIL II

von D. Kelleher

Der Artikel befasst sich mit der Gültigkeit einiger Gesetze, wie jener von Kick, Rittinger und Bond, des dritten Bond'schen Gesetzes und des Holmes'schen Deviationsexponenten zum Kick'schen Gesetz. Verfahren zum Einsatz dieser Theorien zwecks Wahl der Einrichtung, Bestimmung des Energieverbrauchs, und der Betriebsanlagen mit kleinstem Energieverbrauch werden ebenfalls besprochen.

B.C.E., 5, 11, 784. U.D.C. No. 66.011.

WIRTSCHAFTLICH GÜNSTIGSTE KONSTRUKTIONEN VON FERTIGUNGSANLAGEN

von J. J. Taborek, Phillips Petroleum Company, Bartlesville, Oklahoma

Die Ökonomie der Betriebsgewinne und -Auslagen wird als Grundlage für optimale Anlagenkonstruktion erklärt, und der in die Berechnung des Optimums einzubeziehende Fertigungskreislauf wird besprochen. Es golgt eine kurze Übersicht der Methoden zur Optimalkalkulation, nämlich *a*) der klassischen analytischen Methode, *b*) der Methode der unbestimmten Faktoren, *c*) der Methode maximaler Steigung und *d*) wiederholter Produktionsstudien. Die Vorteile und Möglichkeiten dieser Methoden, insbesondere ihre Eignung für Digitalrechenmaschinen und die Möglichkeiten weiterer Entwicklung werden besprochen.

B.C.E., 5, 11, 789. U.D.C. No. 66.047.32:66 074.66

DIE KATALYTISCHE REDUCTION VON OFENGASEN IN SALPETERSÄUREANLAGEN

von W. Fletcher

Eine Übersicht der jetzigen Praxis des Entzugs von Stickstoffdioxyd-Ofengas durch katalytische Verbrennung mit Methan oder Wasserstoff. Die Wirtschaftlichkeit der Energierückgewinnung in Salpetersäureanlagen wird im Zusammenhang mit den Kosten und der Konstruktion der Verbrennungsanlage besprochen.

B.C.E., 5, 11, 791. U.D.C. No. 66.047.791.

ZERSTÄUBUNGSTROCKNUNG VON PIGMENTSCHLÄMMEN

von Ing. G. Kiraly

Eine vereinfachte Annäherung an die Mechanik der Tropfenbildung an Einzelflüssigkeits-Wirbeldüsen und an die Wärmeübertragung zwischen Wärmeträger und Tropfen führt zur Entwicklung eines Versuchstrockners, über welchen Einzelheiten angeführt sind. Die erhaltenen Resultate ermöglichen die Konstruktion einer industriellen Einheit.

B.C.E., 5, 11, 795. U.D.C. No. 542.63:66.061.

DIFFUSION IN VERDÜNNTEN LÖSUNGEN : EINE NEUE BEZIEHUNG

von S. H. Ibrahim und N. R. Kuloor

Ein einfache Methode wurde entwickelt zur Bestimmung der Flüssigkeitsdiffusionskoeffizienten ; diese Methode beruht auf der Voraussetzung, dass der Diffusionskoeffizient eine Molekulareigenschaft ist. Die Beziehung wird durch eine neue, dimensionslose, die sog. Schmidt-Nummer, erarbeitet. Der Artikel gibt eine Erklärung für den in dieser Art von Beziehungen auftretenden Lösungsfaktor, wenn die Kenndaten für Wasser auf andere Flüssigkeiten übertragen werden. Die neue Korrelation ist innerhalb eines durchschnittlichen Fehlers von ± 10% gültig.

Резюме

B.C.E., 5, 11, 766. U.D.C. No. 66.096.5.

РАССМОТРЕНИЕ НЕКОТОРЫХ ВОПРОСОВ КАСАЮЩИХСЯ СООТНОШЕНИЯ ГУСТОФАЗНОЙ ЖИДКОЙ ПЛИТЫ—ЧАСТЬ 2АЯ

М. Лева

Статья обсуждает в начале теплообмен между плитой и внешними поверхностями. Дается краткий отчет о теплообмене между частицами и флюидирующим газом, а также о переносе массы в газе и в жидких флюидируемых системах.

B.C.E., 5, 11, 773. U.D.C. No. 66.022.28.

ТЕОРИЯ И ПРАКТИКА РАВНОМЕРНОГО ИЗМЕЛЬЧЕНИЯ — ЧАСТЬ 2ая.

Д. Коллехор

Обсуждается ценность таких законов как законы КИКА, РИТТИНГЕРА, и БОНДА, в том числе 3ий закон БОНДА и введенный Хольмсом показатель отклонения от закона КИКА. Обсуждаются методы использования теории при выборе оборудования, определения энергетических потребностей и для использования оборудования с минимальной тратой энергии.

B.C.E., 5, 11, 784. U.D.C. No. 66.011.

ТЕХНОЛОГИЯ ОБРАБАТЫВАЮЩЕГО ОБОРУДОВАНИЯ В СООТНОШЕНИИ С ЭКОНОМНЫМ ОПТИМУМОМ

Ж. Ж. Таборек, Филлипс Петролеум Компани, Бартльвилль, Оклохома, США.

Рентабельные методы доходов и расходов приводятся в качестве основы для оптимизации технологии оборудования. Обсуждается вопрос о том, до какой степени следует учитывать схему технологического процесса при расчетах оптимизации. Дается краткий обзор методов вычисления оптимума конструкции, а именно : 1) традиционный аналитический метод, 2) метод неустановленных умножителей, 3) метод наиболее крутого подъема и 4) метод повторного изучения данного положения. Обсуждаются сравнительные преимущества и возможности каждого из этих методов, в частности в области их применения на коммутаторах. Автор указывает также на возможности дальнейшего развития в этой области.

B.C.E., 5, 11, 789. U.D.C. No. 66.047.32:66 074.66

КАТАЛИТИЧЕСКОЕ ВОССТАНОВЛЕНИЕ ХВОСТОВОГО ГАЗА ИЗ УСТАНОВОК АЗОТНОЙ КИСЛОТЫ

В. Флечер

Обзор введенных недавно методов удаления двуокиси азота из хвостового газа при помощи каталитического сгорания с метаном или водородом. Обсуждается экономика восстановления энергии при производстве азотной кислоты, вместе со стоимостью оборудования для сгорания и характеристикой его конструкции.

B C.E., 5, 11, 791. U.D.C. No. 66.047.791.

РАСПЫЛИТЕЛЬНОЕ СУШЕНИЕ ЖИДКИХ ПИГМЕНТОВ

Инж. Г. Киралъ

Упрощенный подход к механике образования капель на одножидкостных ворончатых соплах и к передаче тепла между нагревающим средством и каплями, ведет к конструкции экспериментального сушителя, рабочие данные которого приводятся в статье. Полученные результаты дают данные для конструкции аппарата для комерческого использования.

B.C.E., 5, 11, 795. U.D.C. No. 542.63:66.061.

ДИФФУЗИЯ В РАЗБАВЛЕННЫХ РАСТВОРАХ : НОВОЕ СООТНОШЕНИЕ

С. Г. Ибрагим и Н. Р. Кюлур

Разработан простой метод определения коэффициентов диффузии жидкости ; он основан на предпосылке, что коэффициент диффузии является молекулярным свойством. Соотношение добывается с помощью нового безразмерного числа ШМИТ Разъясняется появление в этом виде соотношения растворительного фактора при переводе данных в воде к данным других растворителей. Новое соотношение пригодно в пределах среднего отклонения ± 10%.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Who Needs Heat Exchange Test Work?

THE National Engineering Laboratory at East Kilbride has announced that it is now in a position to undertake research, development and test work on behalf of individual companies or organisations in the fields of heat-exchange apparatus, heat-transfer problems in general and the relevant physical properties of fluids. The laboratory already provides a number of other technical services to industry. Requests for advice on mechanical engineering problems are welcomed, special investigations arranged, training and conference facilities are provided.

The Heat Division—which will be responsible for the new venture—is already working on fundamental investigations of heat transfer in pipes, in beds of solids and in liquid metals as well as studying the operation and performance of heat exchangers. From the latest announcement it would appear that the division is prepared to consider a wide range of types of work. They include proposals for novel investigations likely to give rise to important developments, full design, construction and operation of apparatus or tests on equipment provided by the sponsoring body. The tests may be on complete units or components and carried out by N.E.L. staff or jointly by engineers from the firm and the laboratory. It will be interesting to see the extent of the demand for these valuable facilities which are backed by an experienced staff in a well-equipped laboratory.

Free Entrainment Behaviour in Sieve Trays

INVESTIGATIONS of the magnitude of entrainment in tray columns as a function of gross system conditions have tended to result in the development of empirical or quasi-empirical relations which are applicable to specific conditions and operating ranges. In a recent report S. I. CHENG and A. J. TELLER of the University of Florida (College of Engineering) have made an effort to evaluate the entrainment phenomenon on the basis of the contributing behaviour mechanisms.

The study was carried out with an air-water system using a sieve plate having 5/32 in. diameter perforations on 15/32 in. triangular pitch with 8% free area; the perforations covered 70% of the tray cross-section. A cylindrical section equivalent to the tray cross-section extended 2 inches below the tray to promote effective distribution of the air. A "drop interceptor" was used to measure both the quantity of entrainment and the size distribution of the entrained liquid droplets. It consisted of a holder box, suspended by a $\frac{1}{2}$ in. diameter rod, containing a 1 sq in. rotating glass slide which could be covered with a magnesium oxide film or to which could be attached a filter paper absorber. The measurement surface was first exposed to the entrainment at various heights above the froth then rotated back to its initial position wtih the exposed surface facing upward. For size distribution studies, the exposed glass slide coated with magnesium oxide was placed in the film section of a slide projector.

An attempt was made to correlate the effects of drop size distribution, projection velocity, drag and gravity on the quality of entrained liquid between trays. The drop size distribution was found to be logarithmic in nature. An equation derived for the entrainment as a function of distance above the froth gave results with an average deviation of 28% from the experimental data. Large deviations were found mainly at greater heights above the foam where the measured quantity of entrainment was in the range of only 0.0002 grams per minute per sq. in. of tower.

Explosion in Flameproof Circuit-Breaker

IT is disconcerting to learn that a certified flameproof circuit-breaker can explode due to a flashover or internal insulation failure. In the last annual report on electrical accidents and their causes* the factory inspectors refer to such a case and draw attention to the limitations inherent in the use of this type of gear. The breaker had apparently been used as standard equipment in a works largely concerned with hazardous materials but was not in a danger area and there was therefore no risk of vapour explosion. Important features of the installation were the unsuitable settings of definite time-limit relays and the arrangements for automatically re-energising a circuit from a standby transformer if the normal supply tripped out; this allowed the breaker, which had already failed, to be re-energised from a different source.

Commenting on the accident, the inspectors point out that no piece of flameproof equipment will withstand for more than a short time an internal short-circuit without losing its flameproof qualities and becoming itself a source of danger. Where there is a general explosion hazard it is obviously even more important than in other situations to ensure, by the proper selection and setting of protective equipment, that internal faults are instantaneously cleared; it must be made impossible accidentally to re-energise defective equipment or circuits. In some chemical processes of course it is important in the interests of safety to resume supply at the earliest possible moment from an alternative source. For such cases the recommendation is that there should be complete duplication of equipment needed in the danger area, together with zone protection against internal faults.

* "Electrical Accidents and their causes" 1959. H.M.S.O. 1960. 5s. 6d.

Interpreting Plant Data by Computers

MODERN chemical plants are generally well instrumented with controllers and recorders. At the recent International Instruments and Measurements Conference in Copenhagen, F. B. SHEPHERD of I.C.I. suggested that the charts from recorders usually get little careful study because of the lengthy calculations necessary to reduce the data contained in them to a comprehensible form. Mr.

Shepherd went on to describe the use of a digital electronic computer to calculate, from plant records, a complete heat and mass balance of a continuous process. This work was the precursor of a study to formulate and solve a mathematical model of the process, with a view to improving the control, performance and throughput of the plant —largely by using apparently redundant data.

In a hydrogenation process, re-circulated gas is mixed with make-up hydrogen before being introduced to the converter. The liquid feed is metered, and the flows and compositions of the make-up hydrogen, the mixed gas feed, the re-cycled gas and the off gas are recorded. Since the complete system can be determined by mass balance from the liquid feed, the make-up flow and composition and the re-circulation rate, four of the eight instruments employed are redundant. Inevitably, if the calculated values of the second four parameters are compared with the measured instrument readings, they will not be in agreement. Since the true flows can only be obtained from the indicated flows by correcting for composition, and the compositions themselves are not precisely known, little further use can be made of the redundant information apart from a very rough estimate of the order of magnitude of the possible errors. With a digital computer, however the powerful methods of numerical iterative procedures can be used. There are eight equations for the individual instrument errors. The problem is to minimise some function of the eight error terms, such as the weighted sum of squares of the errors. The procedure is to solve the four normal equations which are the partial differentials defining the rate of change of the error function with each of the four independent variables. These four simultaneous non-linear normal equations can be solved by the Newton-Raphson method, modified by the addition of boundary rules. The 300,000 calculations required take about one minute on a Ferranti Mercury computer. Heat balances can now be computed, and the best selection of data made to satisfy an overall heat and material balance.

Ceramic-Metal Composites Available For Test

THE unique combinations of properties and the new possibilities of ceramic-metal composites have received increasing attention in recent years. Trial quantities are now being made available for test (by Enamelled Metal Products Corporation Ltd.) of a number of formulations developed in U.S.A. and registered under the name "Nucerite". It is claimed that in one of its formulations, the new material has resisted attack by corrosive vapours at 1300°F. Other claims are high impact strength, tensile strength, resistance to thermal shock and to abrasion. Heat transfer was six to ten times better than that of "other ceramic materials that would be used in high temperature corrosive services." The composition is chemically bonded to steel and to heat resistant metals such as Inconel and Hastelloy in the same way as glasses. It is thought probable that certain reactive metals, such as tantalum, niobium and molybdenum—which maintain strength at elevated temperatures—will also serve as base metals. The unique characteristics of "Nucerite" are attributed to closely controlled nucleation and crystallisation. Agents are used which act as centres of nucleation during a heat treating cycle after applying the ceramic components to the base metal. During the development period, heat exchanger tubing and a number of small reaction vessels have been coated and "satisfactorily tested" but no details have been issued. An extended evaluation period of selected field testing is now planned, to be followed by the establishment of production facilities.

New Regulations for Factory First-Aiders

UNDER a new Order* due to come into force on 1st July, 1961, "first-aiders" in factories with more than 50 workers will have to be registered nurses, enrolled assistant nurses or people holding a certificate of first-aid issued within the immediately preceding period of three years by a training organisation. Details of their names and qualifications and of the date on which evidence of their training was last inspected by the occupiers of the premises, will have to be entered into or attached to the general register maintained by the factory under the Factories Acts.

It may be recalled that under Section 45 of the Factories Act, 1937, first-aid boxes or cupboards should be maintained and readily accessible in all factories. Moreover, in any factory employing more than 50 persons, a person trained in first-aid treatment should be in charge of the first-aid arrangements and should always be readily available during working hours.

* First-aid (Standard of Training) Order, 1960, S.I. 1960 No. 1612. H.M. Stationery Office, 3d.

Re-Thinking Comminution

AT present all commercial crushing and grinding, and nearly all comminution laboratory testing, is accomplished principally by converting mechanical energy into strain energy into heat. FRED C. BOND has attempted a restatement of the basic principles of comminution starting by considering the efficiency of this conversion in relation to the efficiency of particle size reduction. The amount of effective strain energy conversion is designated in his paper* as the "energy register." As a first principle, Mr. BOND suggests that in analysing all comminution problems, this equation should be used:

$$\text{energy input} = \text{energy register of product} - \text{energy register of feed}$$

This energy register is thus the amount of energy which has passed through the material as strain energy and registered as particle size reduction. It does not correspond to energy content as usually understood.

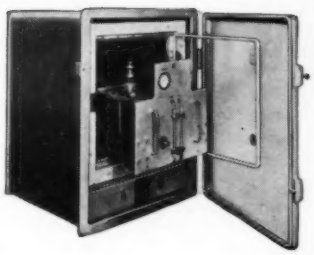
The second principle is that the total effective work input required to break a stated quantity of rock is regularly proportional to the total length of the crack tips formed, or the square root of the total surface area formed, from a theoretically infinite feed size. In practical grinding operations the numerical difference between the specific work input required with a piece of rock feed weighing one ton and a piece of theoretically infinite size is insignificant. The second principle can accordingly be restated in these terms: the effective kilowatt-hours required to grind a ton of rock from one piece to any product size d is regularly proportional to $1/\sqrt{d}$.

Finally, the third principle of comminution theory deals with the flaws in individual particles. It is formulated in three linked clauses. (a) Flaws are present in all size ranges of crushed and ground products. (b) The weakest flaw in a particle determines its breaking strength and the number and size of the product particles formed. (c) The weakest flaw in a particle does not determine the specific work input required to reduce it from a stated feed size to a stated product size.

This is an interesting attempt to derive a relationship between the useful energy input and the product particle size from a given feed: for those working in this field it would be useful to read the author's argument in full.

* *Mining Congress Journal* August 1960.

Process Analyser



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The instrument draws a sample from the process stream, analyses it and presents the results on a recorder. A versatile control system selects and attenuates a number of individual peaks or gives a complete chromatogram.

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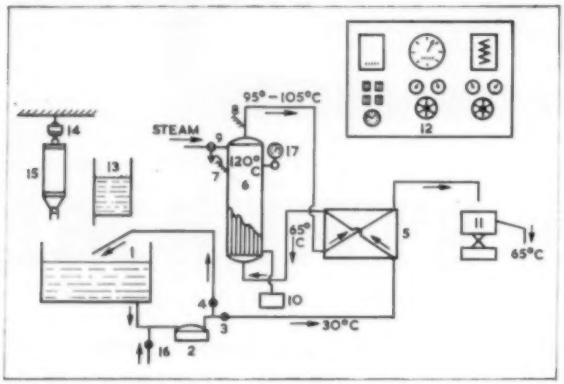
SCIENTIFIC PYE INSTRUMENTS

New Yeast Production Process

ORTHOPHOSPHORIC ACID—and no phosphate—is used as a source of P_2O_5 in a new Czech process for manufacturing yeast*. The other raw materials are molasses and ammonia liquor for the preparation of broth. Only the calculated quantity of phosphoric acid is used. The broth produced is clear; after dilution in the fermentor all impurities stay in solution and the cells are in a good physiological state. Full scale experiments have proved that the cost of raw material works out 20% lower than in earlier processes in spite of the increased cost of P_2O_5 from phosphoric acid as compared with that from superphosphate. This is because sulphuric acid is no longer required, ammonia liquor is cheaper than ammonium phosphate and losses of available P_2O_5 for fermentation are very low. Other advantages are easier treatment of effluent, easier handling of raw materials (all are liquids), possibilities of full automation, lower steam usage in the continuous process and lower usage of anti-foaming fat. The yeast produced is said to be of fine colour, very active and has good keeping qualities.



Flow streams for continuous preparation of broth.

1–dilution vessel for molasses, 2–pump, 3, 4–valves, 5–heat exchanger; 6–tube heater, 7, 8–thermometers, 9–air operated valve, operated by temperature controller, 10–steam trap, 11–centrifuge, 12–control panel, 13–measuring vessel for acid, 14–water inlet, 15–molasses inlet, 16–steam injection, 17–pressure gauge.

The equipment for continuous preparation of broth consists of a central vessel containing diluted molasses and phosphoric acid and a pump used for recirculation of the diluted molasses (and hence mixing) and for transfer into the process. The pumped diluted molasses to the process go through a heat exchanger countercurrent to hot molasses from a plate type steam heater. The cooled molasses pass through a centrifuge where the coagulated impurities are separated and into a storage vessel from where they are metered automatically into the fermentors.

* Czechoslovak Patent PV 7505/59 discussed in *Kvasny Prumysl* 1960, vol. 6, No. 4, p. 81, by Josef Tomisek.

Natural Gas at Whitby

FOR Britain it is news that a town is to be supplied with gas drawn from a natural gasfield. Two wells near Whitby have proved to have sufficient reserves to justify installing plant to supply the town. From the well head the gas—mainly methane and having a C.V. of 1000 Btu per cu ft—flows to a separator to remove any free water then on to a horizontal natural-gas-fired water heater used to heat the gas. This is intended to overcome freezing conditions which could arise from adiabatic expansion of the gas forming ice and methane-hydrate which might clog the pressure reducing equipment. The tube bundles of the heater are arranged in two passes. In the first the gas is heated to 150°F then cooled to approximately 70°F on being expanded from 1900 psi to 1000 psi. After passing through the second tube bundle the gas is re-heated to 150°F and subsequently cooled to 70°F expanding from 1000 psi to 200 psi. To protect the transmission line, two safety valves have been incorporated in the surface plant—a safety shut-off valve set at 230 psi and a safety relief valve at 260 psi.

At the Whitby Gas Works, the gas passes through oxide purifiers then to a P.G. Hercules plant for reforming to hydrogen and carbon monoxide. It is enriched with methane to a gas of 500 Btu per cu ft, specific gravity 0.54, which wholly replaces the previous town gas supply. As a standby in case of temporary interruptions of flow of natural gas from the wells, there is equipment for reforming butane to gas of the same approximate composition.

Fuel Economies in Chemical Factories

IN its attractively produced Sixth Progress Survey, the National Industrial Fuel Efficiency Service reports on results of 169 surveys in chemical factories consuming over 800,000 tons of coal per annum. Among the examples given are these:

★ From a pot fusion process, gases leaving an oil-fired furnace at about 1100°C. were led into an adjacent pneumatic drier, which had previously been directly fired. The savings amounted to nearly £1000 a year.

★ Turbo-blowers and air compressors are often found to be working inefficiently because silencers or filters for the intake air are of the wrong size—or the filters have become choked. In one works, the pressure drop was reduced by 10 in. w.g. by fitting new silencers, and over £2000 per annum was saved.

★ A single-effect evaporator was found to be using over 1½ lb. of steam to evaporate 1 lb. of water. Installing a thermo-compressor unit halved the steam consumption, saving £200 a year for an expenditure of less than £100.

★ Cooling water at 188°F. previously run to waste from the condenser on a still, was supplied for use as hot boiler feed saving £950 a year.

★ Typical savings on covering storage tanks containing heated liquids were £200 a year by fitting a wooden cover to an outdoor tank in a chalk hydration process; over £3000 a year by insulating large tanks for storing hot water.

Overall, the heat economies averaged 15.2% in boiler plants, 24.3% on process plants.

Measuring Dust Emission from Steelmaking

IN boiler house practice it has been found possible to monitor suspended matter in the flue gas by continuously measuring the optical density. D. H. CHRISTIE and his colleagues of the United Steel Companies have confirmed that similar methods of control are practicable for the fine fumes from new steelmaking processes. The monitoring of these emissions is necessary for the design of fine fume cleaners. The new problems arise principally from the use of oxygen, for example, in the desiliconising of pig iron, in oxygen blown steelmaking processes—such as open hearth and electric arc—and for the deseaming of ingots. These processes yield large volumes of fine dust, mainly iron oxide. Because of its sub-micron size this is far more difficult to deal with than smoke from the combustion of fuel. Depending on the concentration, the effluent velocity and local atmospheric conditions, the fume emerges from

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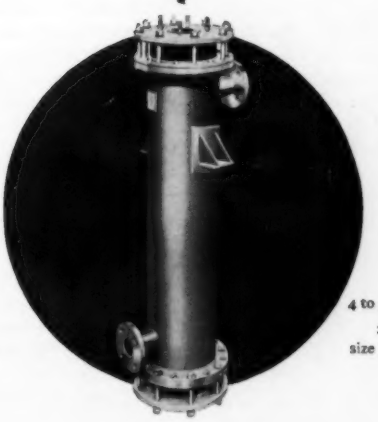

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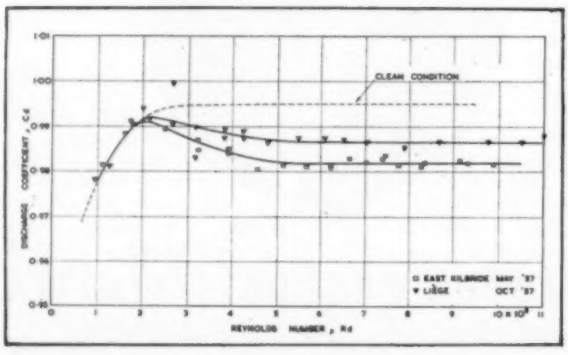
plant stacks as a brown or deep red plume. The obscuration of light by a cloud of fine material is much greater than that for a similar mass of coarse dust, and this often gives an exaggerated impression of the mass of effluent material.

In a paper to the Clear Air Conference at Harrogate, Mr. CHRISTIE presented results obtained at a sampling point 50 feet up a 170 foot stack. To produce a criterion independent of local conditions the chimney diameter and gas temperature were eliminated from the results which were replotted as optical density per foot at 0°C versus dust loading per cu ft of gas at N.T.P. On this basis the optical density proved to be approximately proportional to the dust loading. Consequently for normal practice with either the electric arc or open hearth furnace it is possible to estimate the dust concentration in the waste gas from measurements of optical obscuration. Relationships for two furnaces examined were similar, but there were slight differences in the slopes of the characteristic lines. These variations were thought to be due to different size distributions. Experiments have now been planned to examine the specific effect of particle size distribution on optical density.

Sources of Error in Venturimeters

IN our leader column we refer briefly to the final satisfactory results of a joint study on four classical venturimeters by Dr. E. A. SPENCER of the National Engineering Laboratory and Mr. GUY THIBESSARD of the General Hydraulics Laboratory, University of Liège. But these results followed a set of earlier ones which emphasised the importance of a number of factors generally applicable to the calibration of flowmeters. Each of the two collaborating laboratories had two meters suitable for installation in a 100 mm diameter pipe line, the area ratios of the meters being 0.25 and 0.5. Using cold water a large discrepancy was found in the *initial* results of the Liège and N.E.L. tests on the 0.5 Liège meter attributed mainly to the difference in the internal surface condition of the meter in the two tests. Generally it was notable that the difference caused by the roughening of the meter became less as the Reynolds number decreased and, below about 200,000, the roughening caused by the build-up of deposit left the discharge coefficient unaffected. After detailed discussion the authors comment that the effects on dimensions of the fouling meters during use undoubtedly deserves a more thorough investigation since normally the flow-rate calculations will be based on the original clean dimensions. If, however, a quantitative correlation between roughness height or type of deposit and the discharge coefficient change could be found, the effect of change of diameter and that caused by friction losses could be deduced.



Effect of dirt on discharge coefficients of venturimeters.

Chemical Engineers Can Help Plan a Syllabus

A UNIQUE approach has been adopted by Professor EDGEWORTH JOHNSTONE—who has recently taken up his post at Nottingham University—in preparing his course. In order to find out how frequently the various academic subjects are used in day-to-day practice he has issued to all members of the Institution of Chemical Engineers a questionnaire. This lists 24 sciences and techniques which could be taught at a University. Members are asked to mark any used during the previous five working days. Provided that sufficient replies are received, Professor Johnstone hopes to obtain an estimate of the relative utility of each subject from the frequency of its use during the week. The information will be used to help him in planning his syllabus.

What engineers actually do is of course not necessarily what they ought to do for the most economic results. Nevertheless it will be a major contribution to the development of the subject to find out what branches of knowledge are currently applied and we should not be surprised if this initiative does not soon have the compliment of being copied by other teachers or learned bodies.

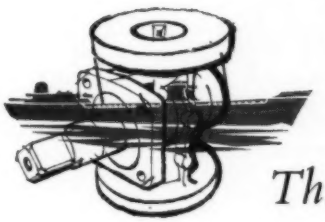
There was another important aspect. The meters manufactured and used for these tests were to a more rigid specification than normal but, even so, some deviations in profile were subsequently found. The parallel portions had very slight tapers, and though it can be assumed that these will always be within the specifications laid down in the National Codes, it is desirable that the positions of the control diameters should be specified. As a result of the present series of tests the authors suggest that the control diameters should be standardised to be those at the planes of the pressure tappings and not averages of the whole section. Furthermore the upstream, convergent and throat sections should be manufactured as one unit and the upstream section made at least one pipe diameter long to avoid any local disturbances from irregularities in matching pipe to meter. One can appreciate the final comment that the exchanges of equipment between N.E.L. and the University of Liège had been "productive of much more than a simple duplication of test results."

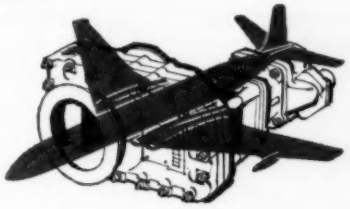
Welding in the Soviet Union

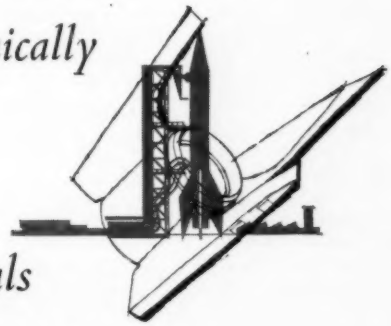
AFTER a recent visit to the Soviet Union a group of British welding experts concluded that the Russians have a clearer realisation of the key role played by welding than we have. There were some outstanding achievements, but there are also certain spheres where work is not as far advanced as in this country. Welding of aluminium alloys by the inert gas metal arc welding process appears to be further advanced in this country than in the Soviet Union. On the other hand the emphasis there on submerged arc welding has led to the development of methods and suitable fluxes for the welding of aluminium alloys, titanium alloys, and of copper. The joints appear to be of good quality and are claimed to have properties not very inferior to those of the parent material.

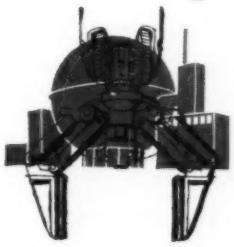
The group of four senior members of the staff of British Welding Research Association led by Dr. R. WECK, Director, visited the five Institutes which between them are responsible for about half the papers published in the Russian welding journals. They also went to the Welding Exhibition in Moscow within the permanent Exhibition of the

Kanigen *a hard, non-porous corrosion-resistant plate, gives complete uniform coverage even to the most intricately shaped parts. Thickness can be controlled to fine limits. Being chemically deposited Kanigen can be applied to practically all metals in commercial use. It can also be applied to non-conductors such as plastics and ceramics.*









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Economic Achievements of the National Economy. The group had no opportunity of judging trends in pressure vessel design and thought it a weakness that there appeared to be no attention to codes and design. This issue would apparently only arise there if the Government standards organisation asked for this type of work.

It may be noted that the Association in collaboration with the Institution of Mechanical Engineers is to organise a Symposium on "Pressure Vessel Research towards Better Design" in London on 18th January, 1961. About twelve papers covering research and design will be discussed during the one-day meeting. Papers will include comparisons of continental and British practices and of design codes.

Measuring Power Requirements for Mixing

THE direct method of determining power used in mixing is to measure the requirements of the motor driving the mixer shaft on- and off-load and finding the difference. However, high accuracy cannot be obtained by this means, especially in the case of 3-phase motors and consequently forms of indirect measurement have been devised employing torque and calorimetric measurements. For the former a number of types of dynamometer has been developed. Primary torque may be measured by attaching one dynamometer disc to the driving part of a mixer shaft and the other to the driven part, the two being connected by springs. The lower disc changes position relative to the upper during the starting period; when equilibrium is established, both discs rotate together. The measurement of the torsion angle between the discs in rotation is the chief difficulty in measuring primary torque. It can be achieved optically by means of a stroboscope, or electrically through a valve rheostat mounted between the dynamometer discs.

In a recent paper* HENRY BLASINSKI of the Department of Apparatus for the Chemical Industry of Lódz Polytechnic has introduced two modifications of this method. One depends on measuring voltage or current density of an induction current produced in secondary windings between the dynamometer discs in the field of a primary winding fed by a.c. Expressions have then been derived for calculating the torque. A second modification, claimed to increase accuracy is based on the principle of making the torque of the mixer a function of the frequency of the generator. In this case the measuring system consists of a movable and an immovable part. The first comprises a modulated generator with feed, a variable capacitor and an aerial. The second consists of a receiver, a feed and an aerial. The two parts have no mechanical interconnection. The frequency of the generator is changed by means of a variable capacitor.

* Przemysl Chemiczny 1960 Vol. 39 No. 7, p.414.

Are Safety Posters Any Use?

AFTER examining the results of a pilot experiment Mr. R. H. COLLCUTT, Head of Operational Research at B.I.S.R.A.* has concluded that posters can be an effective tool of accident prevention. The experiments with new specially designed safety posters were carried out in seven works split into two groups of three with the remaining works as a control. In the first group of three all three posters went up together; in the second group each of the three posters went up in turn at fortnightly intervals. There were no posters in the control works. The issue chosen was that of persuading workers to hook the slings on cranes. To give a base line there was a count of how many slings were hooked back, and of how many were left swinging, for five weeks before the posters were put up.

In the outcome more slings were correctly hooked in all experimental works; in three works the percentage increase was round about 10%. In the control works, on the other hand, there was actually a small drop during this time. Furthermore results proved to be lasting. Far from the poster effect wearing off there was actually a further upward swing in all works bar one after the end of the initial trial period. The average further improvement was 4.5%. Details of this valuable research with its pointers for several industries are in B.I.S.R.A. Report OR/HF/15/60 "An Experiment on the Effect of Specially Designed Safety Posters", and a popular account has appeared in "Safety" No. 10, published by the British Iron and Steel Federation.

* British Iron and Steel Research Association.

DIARY

The Institution of Chemical Engineers

October 28. *South Wales and Monmouthshire Group* with the Society of Chemical Industry. At University College, Cardiff. "The Calculation of Reactor Volume from Laboratory Kinetic Data," by R. F. Strickland-Constable. **7 p.m.**

November 1. *North Western Branch.* At The Blossoms Hotel, Chester. "Prediction of Ternary Data from Binary Systems," by E. Evans. **7.30 p.m.**

November 3. *Graduates and Students Section, Manchester Centre.* At Manchester College of Technology. "Packed Columns," by P. J. King. **7 p.m.**

November 8. At Geological Society, London, W.1. "The Dynamic Response of a Distillation Column to Changes in the Reflux and Vapour Flow Rates," by W. D. Armstrong and R. M. Wood. "An Introduction to the Theoretical Evaluation of the Frequency Response of a Distillation Column to a Change of Reflux Flow Rate," by W. D. Armstrong and R. M. Wood. **5.30 p.m.** Tea 5 p.m.

November 9. *Graduates and Students Section, Midlands Centre*, Department of Chemical Engineering. At the University, Birmingham 15. "Development of the Tonnage Oxygen Process," by W. F. Castle. **7 p.m.**

November 16. *North Western Branch.* At the Houldsworth School of Applied Science, Leeds 2. "Electrical Hazards in the Chemical Industry," by F. Clark. **6.30 p.m.**

November 22. *North Western Branch.* At Chemical Engineering Lecture Theatre, Manchester College of Science and Technology. "New Developments in the Bulk Supply of Chemical Reagents." **3.30 p.m.**

The Institution of Mechanical Engineers

November 9/10. Symposium on the Use of Secondary Surfaces for Heat Transfer with Clean Gases. Linked with the A.S.M.E.-I.Mech.E. International Heat Transfer Conference to be held in 1961-62. **November 9.** Cross Flow. **2.30 p.m. November 10.** Fuel Elements. **10 a.m.**

Society of Chemical Industry

November 7. *London Section.* At 14 Belgrave Square, London, S.W.1. "The Future of Chemicals from Coal," by Dr. W. Idris Jones. **6.30 p.m.**

November 8. *Chemical Engineering Group.* At 14 Belgrave Square, London, S.W.1. "Manufacture of SO_3 and Strong Oleum," by J. C. MacFarlane. **6 p.m.**

Special Course

November 9, 16 and 23. At University of London King's College. Public Lectures on Vibration Mills and Vibration Milling, by Dr. H. E. Rose. **5.30 p.m.**

EXPANSION PROGRAMME FOR UNIVERSITY COLLEGE OF SWANSEA

THIS year marks the opening of a decade of dramatic change for the University College of Swansea for the Governors of the College have embarked upon a bold and imaginative development programme which will cost £11 million in buildings alone. As things stand at present, though the competition for places in the University College is reassuring, there are not nearly enough places to satisfy the demand, which is growing yearly. This, and national requirements, underlie the decision of the College Council to double the size of the College during the next ten years, a measure which is expected will lead to the accommodation of nearly 3000 students.

Something like two-thirds of this number will be studying either pure or applied Science, and the proportions of each will be about equal. The remaining students will be studying Arts subjects, and the courses will include social studies, such as History, Economics, Political Theory and Government. In pure Science there are two main groups of study; Mathematics and the Fundamental Sciences of Physics and Chemistry. In addition there are the Natural Sciences of Botany, Geography, Geology and Zoology.

In the Applied Science group there are at present three departments; Metallurgy, Engineering and Chemical Engineering and all three departments will extend considerably. Metallurgy is of special importance to the region, and this was one of the pioneering departments in the College. It provides, at an advanced level, good facilities for studying fabrication metallurgy; and current research ranges from the deformation and corrosion of metals to the properties of slags and refractories.

The Engineering Department, greatly expanded in recent years, represents the Civil, Mechanical and Electrical branches of the science, each with a professor at its head.

Research in Mechanical Engineering includes work on problems of heat transfer, which may lead to the development of new types of compact heat exchanger, on problems of metal fatigue, and on the development of automobile transmission systems.

The Department of Chemical Engineering, opened in 1955 and now admitting 30 students each year, has already established research in the flow of non-Newtonian fluids, mass transfer and the control of distillation columns. A notable feature of the honours school is the generous provision by industry of facilities for practical training.

The University is guided by the precept that its success is to be judged not only by the men and women it sends out into the world but by the extent and excellence of its research, for without this vital stimulus the quality of teaching is likely to be impaired.

Needless to say, this extensive programme of expansion requires money. Already the Treasury (through the University Grants Committee) has sanctioned very large sums —between four and five million pounds—for building and equipment in the years 1957-63. But the College Council has very heavy financial obligations, and the College itself is expected to make a substantial contribution—at least £500,000—both to current building and to further expenditure that will be needed to complete its programme after 1963.

So far, gifts amounting to £200,000 have been given including large sums from such companies as The Steel Company of Wales Ltd., BP Refinery (Llandarcy) Ltd., British Nylon Spinners Ltd., Mond Nickel Co. Ltd. and Imperial Chemical Industries Ltd.

It is to be hoped that through the generosity of industry and commerce and the loyal support of former students, as well as those closely associated with the work of the University, that the balance will be quickly contributed.

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THE FUTURE

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Bradford Institute of Technology

Head of Department of Chemical Engineering

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Measuring Flow

IF an engineer engaged in processing is called upon to measure flow in a closed pipe, his most likely solution will be an application of the well-tried orifice meter, preferably with a differential-pressure cell. For special cases a Venturi type of meter—or one of its developments—might be applied, sometimes a rotameter device and for large gas flows possibly a positive or semi-positive meter.

Yet there is now available a wide range of instruments and methods—some of general utility, others of rather specialised application. A valuable survey of this ground has recently been made as a result of the initiative of the National Engineering Laboratory at East Kilbride (near Glasgow) in organising a symposium where they were able to muster 29 papers from leading workers in flow measurement, drawn from eight countries. Total attendance was 160, and roughly a quarter of the number registered came from 16 countries overseas. Subject-matter branched out from the familiar methods to the less familiar, from the kinds of piping familiar to chemical engineers to those handling the flow rates involved in rivers.

The National Engineering Laboratory itself was much more than a formal host on this occasion, for its workers have made major contributions to flow measurement and the proceedings actually opened with an N.E.L. film. The laboratory is excellently equipped with accurate flow devices designed and constructed from its own resources. Furthermore, it has now built up a stock of experience and of trained personnel which give it international standing in the subject. It should also be noted in passing that, during 1959, no fewer than a hundred tests were carried out for industry and government in the field of calibrating venturimeters, orifice plates and turbine-type flowmeters or determining head loss characteristics of valves. In the course of this calibration work a new method of computing flowmeter test results was developed; tables of correction factors were prepared which allow routine computations to be carried out with a considerable saving in time. It is our impression that industry is insufficiently aware of these services.

In the formal proceedings of this Symposium the laboratory supplied the rapporteurs at several sessions and two papers, both collaborative efforts with other organisations. One of these—based on work by Dr. E. A. SPENCER of N.E.L. and M. GUY THIBESSARD of Liège University—was a comparative study of four classical venturimeters. A high level of agreement between the results from the two cold water calibration systems was obtained after the initial stages. The second paper was devoted to assessing the value of the isotope dilution method—an analogue of the classical salt dilution techniques which have had considerable attention at East Kilbride. In this contribution C. G. CLAYTON, ANNE M. BALL, W. E. CLARK (of the U.K.A.E.A. Wantage Laboratory) and Dr. E. A. SPENCER described how they compared their results against an absolute standard—an accurately calibrated system based on weighing the water flow. With turbulent flow in a 20 in. diameter pipe at flow rates up to 20 cu secs the means of measurements made at sampling positions 110 diameters and 220 diameters away from the injection point showed a deviation of less than 1 per cent from the absolute value. They concluded that large water flow rates can conveniently be measured using radioactive isotopes. Answering one obvious objection, it was pointed out that, if elementary rules are followed, radiation hazard is reduced to negligible proportions.

Increasing interest in the Gibson method was reflected in a section devoted to this technique in which a change of momentum is equated to the impulse given by a turbine gate and stop valve during a controlled reduction in flow. Professor KURT ALMING, of Trondheim, Norway, reported that until recently current meters were most commonly used in that country for flow measurement in closed conduits. However, as part of the new developments in the layout of modern power plants, the Gibson method has received detailed attention.

Papers dealing with techniques that could not be classified together under any one unifying theme were presented at one session under the anonymous title "Special Methods". The mass flowmeter (discussed by P. SCANES of George Kent Ltd.) has the advantage of eliminating the need for separate density measurement and subsequent computing. Two systems have emerged. One provides a differential pressure and the other a mechanical force or torque proportional to the mass flow rate. At this session, F. E. FISHBACHER (of British Scientific Instruments Research Association) gave the results of tests on the ultrasonic flowmeter, based on the phase difference between ultrasonic signals transmitted with and against the flow. This showed repeatability with a standard deviation well below 1 per cent of full scale readings. Rounding off the group were papers from H. GEHRE of Germany and J. M. A. SMITS of Netherlands, who collaborated in studying a turbine-type gas flowmeter developed by the first author, and a final one on the magnetic flowmeter. The latter device can be used to measure the volume flow of a wide range of liquids having a certain minimum conductivity. B. W. BALLS and K. J. BROWN of Foxboro-Yoxall Ltd. set out examples of its applications—particularly for fluids bearing fibres and solid particles—and some of the restrictions on its use.

Though many of the papers will have more relevance to the hydraulics man, chemical engineers have ample cause to congratulate N.E.L. on this venture with its pointers to several possible new instruments to take into account in future plant designs.

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PART II

SOME CONSIDERATIONS OF DENSE-PHASE FLUIDISED-BED CORRELATIONS

by MAX LEVA*

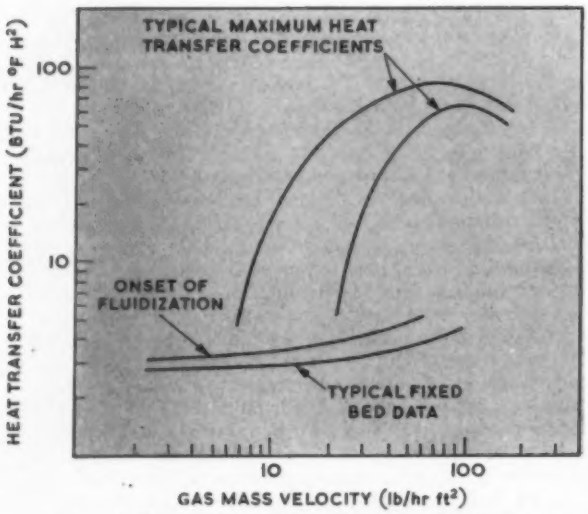

Fig. 1. Order of magnitude of fluidised-bed heat transfer coefficients and comparison with fixed-bed data.

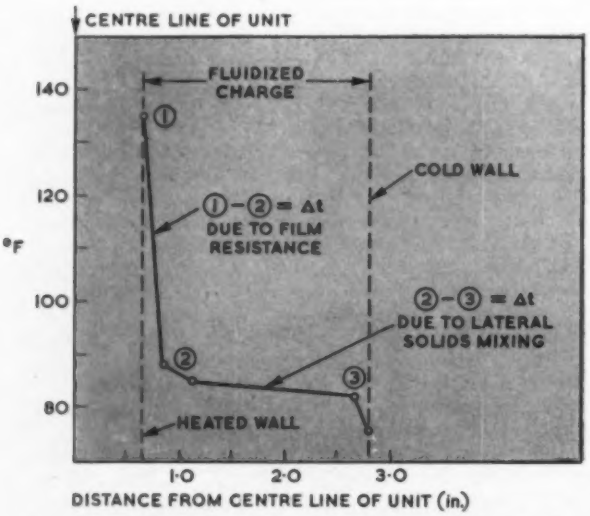

Fig. 2. Typical radial temperature profile in annular space; data of Baerg et al.[3]

IN the preceding paper attention was given to correlations that pertain to the mechanics of the dense-phase fluidised bed. In this paper heat transfer and mass transfer will be discussed.

When considering dense-phase fluidised-bed heat transfer, we are concerned with:

(1) heat exchange between bed and an *exterior* heat transfer surface;

(2) heat exchange between bed and an *interior* heat transfer element; and

(3) heat exchange between particles and the ambient fluid.

Obviously, when considering mass transfer we shall only regard exchange of mass between the particles and the ambient fluid.

Heat Exchange between Bed and Exterior Surface

This case represents by far the simplest situation. As a consequence, the data have yielded quite readily to a general treatment. This is so because for the equipment in question there are no internal elements and hence the solids flow pattern, which is known to affect temperature distribution in the bed, is not specifically influenced. This, however, does not preclude the possibility that through faulty placement of thermocouples and other probing equipment the flow pattern might in some instances have been affected, thus leading to data difficult to correlate.

To begin with, a brief discussion of order of magnitude will be instructive. Fig. 1 reports some typical fluidised-bed data as well as non-fluidisation data for the same flow range and bed. This latter condition may either be brought about by artificially restricting the top of the bed, or, simpler still, the gas may be passed downward instead of upward. It appears that for the region of incipient fluidisation the coefficients are essentially fixed-bed coefficients. As mass velocity is however increased the coefficients increase at a very rapid rate. At higher flow rates the rate of increase lessens, a condition which leads to a heat transfer maximum. At the mass velocity sufficient to create this maximum the fluidised-bed data are roughly 10-12 times those of the fixed bed. Without exception, and regardless of whether exterior or interior heat transfer is involved, it has been found that all data show these characteristics. The maximum heat transfer coefficient may occur at a considerable range of mass velocities, depending, of course, on specific characteristics. In all cases do the coefficients show the marked discontinuity and increase as the bed begins to stir

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initially, in due course of fluidisation. This has been particularly well described by Baerg and co-workers.[1] In fact, these researchers suggested that the discontinuity of the heat transfer coefficients to ascertain the onset of fluidisation be used.

One could hardly wish for more significant characteristics to point to a heat transfer mechanism than are given by these fluidised-bed data. Hence it was quite logical to assume that the movement of the particles will tend to disrupt a film between the bed and the inside wall. By virtue of this disruption, the resistance to heat flow will then be lessened. This will lead to increased coefficients. The increase will be especially significant if the resistance offered by the film is the main resistance. Possible mechanisms along this line have been discussed in detail elsewhere,[6, 12, 19] and let it suffice to say that actual top-to-bottom mixing studies have indicated that the velocity of particles, moving *en masse*, permits the correlation of these types of data.[11]

Despite this obvious film effect, the extent of the lateral as well as vertical solids mixing in the vessel must be appreciated. That these agencies are significant is indicated by the unusual flatness of the temperature profiles in well-fluidised beds. Shown in Fig. 2 is a typical radial temperature profile.[1] The steep drop near the heated wall is an indication of the film resistance already mentioned. The central flat portion of the data emphasises the excellent radial mixing that must prevail.

A vertical temperature profile is shown in Fig. 3.[12] Heat is being added to a bed through a surrounding steam jacket. The rapid temperature rise for the first few inches of the bed may, of course, be due in some part to an end effect; however, the main reason for the rapid rise in temperature is the considerable heat transfer coefficient and the appreciable top-bottom mixing that must prevail. This vertical mixing in the main section of the bed is also supported by the relatively flat profile, once the lower bed section has been passed.

An understanding of the nature of this vertical temperature profile is of fundamental importance as far as evaluation of heat transfer coefficients is concerned. In fact, it may be stated that a study of heat transfer between a fluidising bed and a heat transfer surface involves merely the establishment of these gradients. Thus if temperatures were only measured at both ends of the bed and if these were used for evaluating a logarithmic mean temperature difference, to be employed in turn for evaluating coefficients, these resulting coefficients would be *much lower than actual coefficients*, because the logarithmic temperature difference, only valid for a system with no back-mixing, is much larger than the actual temperature driving force. The true temperature difference must, of course, be evaluated by graphical integration and the value thus obtained for the data shown in Fig. 3 is equal to 8.46°F, whereas the logarithmic mean value calculated from terminal data would have been 63°F. This matter of evaluating the proper driving force is mentioned here for two reasons. First, it sheds some light on the nature of the measurements that are required in fluidised-bed heat transfer studies and, secondly, it shows the seriousness of the error that would have resulted as far as the numerical value of the coefficients is concerned, had they been based on a logarithmic mean driving force. It is of interest to point out that in mass transfer studies between fluidised particles and fluid the situation is analogous, and in this field logarithmic mean driving forces *have* been used, with the result, of course, that the reported mass transfer coefficients appear to be much lower for the fluidised beds than for the fixed beds. This, of course, is not true. The resulting distortion naturally was not intended, but was due to both oversight as well as experimental difficulties. This will be briefly referred to later.

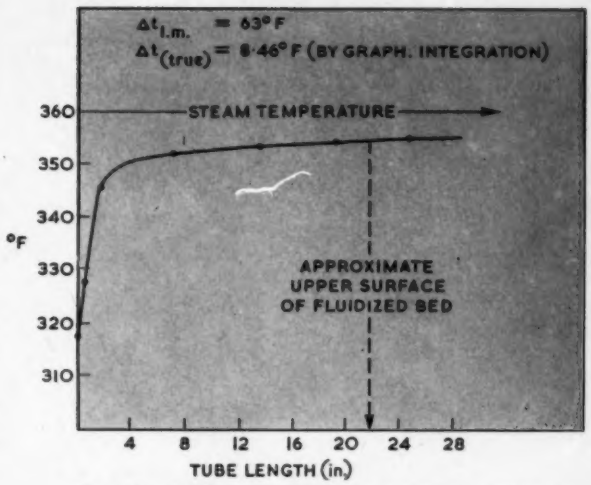

Fig. 3. Typical vertical temperature profile in cylindrical bed.

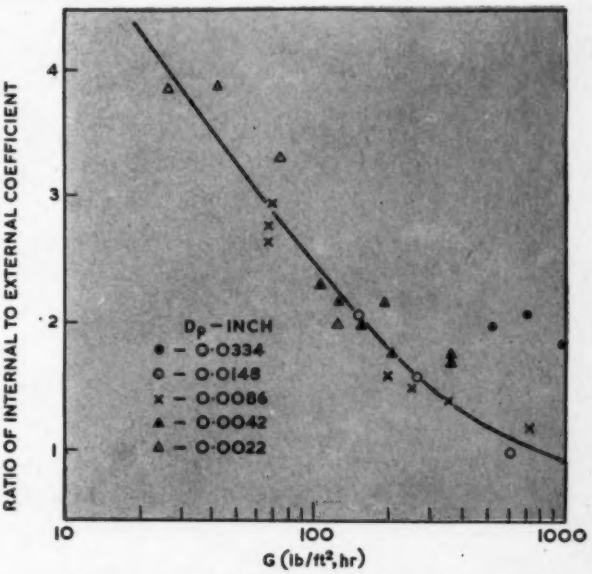

Fig. 4. Internal-external fluidised-bed heat transfer coefficient versus mass velocity.

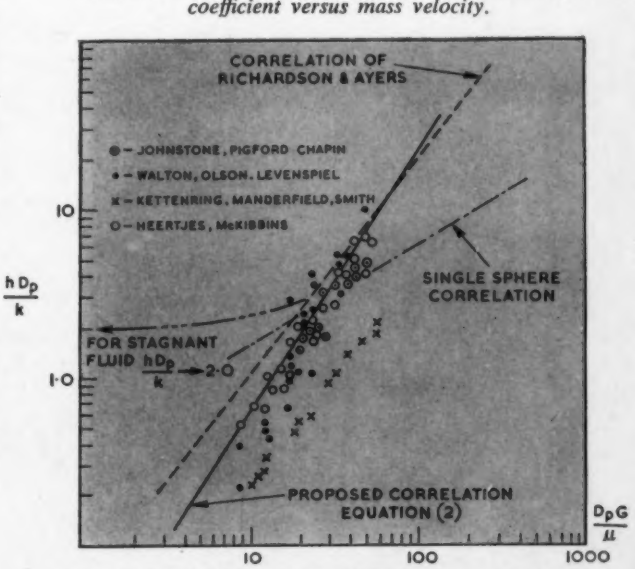

Fig. 5. Particle-fluid. Fluidised-bed heat transfer data.

A generalised correlation based on the majority of fluidised bed-exterior surface data[3, 7, 9, 10, 16] and conceived by the above indicated mechanism[15] is as follows:

$$\frac{h\,D_p}{k} = 0.16\left(\frac{c_S\,\rho_S\,D_p^{1.5}\,g_c^{0.5}}{k}\right)^{0.4}\left(\frac{G\,D_p\,\eta}{\mu R}\right)^{0.38} \quad \ldots.(1)$$

Fluidisation efficiency, η, and bed expansion ratio, R, are evaluated from Figs. 4 and 5 of the preceding paper. The other quantities may be expected to be available from process specifications.

It is to be noted that the correlation does not apply to the onset of fluidisation, for which condition a coefficient of zero would result. Other limitations dictated by the supporting experimental data are as follows:

Particle diameter, D_p (in.)	0.0015-0.0335
Tube diameter, D_t (in.)	2.0-4.73
Solids density, ρ_S (lb/cu ft)	37.5-500
Solids specific heat, c_s (Btu/lb °F) ...	0.034-0.178

As far as flows are concerned, Equation (1) may be safely adopted within a range of $2 < G/G_{mf} < 20$.

Heat Exchange between Bed and Interior Surfaces

Equation (1) just presented has been found to apply well to externally heated or cooled equipment. The largest vessel from which data in support of the equation have come is 4.73 in. Such a column may be sufficient for many pilot-plant studies, but it will hardly be sufficiently large to accommodate many industrial operations. With larger diameter equipment, say columns of up to 8 or in some exceptional cases say 12 in. an extrapolation of Equation (1) may perhaps be permissible. However, when the rate of heat exchange is high, and perhaps critical, an externally heated or cooled column must be abandoned for a unit that carries internal heat transfer elements. With such parts inside the fluidising bed, the solids flow characteristics must now be expected to be different, with a corresponding effect on heat transfer rates. The changes which are thus introduced may be sufficiently severe that Equation (1) will for certain operating conditions barely give the correct order of magnitude of the heat transfer rates. This may be appreciated from some interesting data of Toomey and Johnstone.[16] They operated a unit in which heat was supplied by a centrally located calrod heater, to be removed by a surrounding water jacket. The equipment was built in such a way that for the same flow rates simultaneous interior heating and exterior cooling coefficients could be observed. It is important to re-emphasise that both these coefficients pertain to the same bed, but due to their difference will indicate the extent to which conditions, as far as heat transfer is concerned, may vary in the same bed operated under these same flow rates. Fig. 4 presents the ratios of internal to external heat transfer coefficients for this equipment in relation to mass velocity. It will be noted that for a mass velocity of about 30 lb/hr ft^2 the internal coefficients are about four times as large as the exterior coefficients. Only as mass velocities increase substantially do the coefficients tend to become equal. Furthermore, as mass velocity increases, the scatter increases, pointing to the appearance of unstable conditions, such as perhaps slugging in the bed. It must be comprehended that the data of Fig. 4 are specific and that for other designs a different behaviour may be obtained. However, the data do indicate the important fact that even within the same bed, when operated under the same flows, the agencies which bring about exterior and interior heat flow may be of very different intensity. It is well to keep this in mind when we are called upon to pass judgment on generalised correlation efforts of data of this sort.

All experimental studies relating to internal heat transfer employed one single immersed element, which varied in diameter from 0.25 to 1.33 in. This is quite an impressive variation, but so is also the variation which accompanies the heat transfer coefficients. Unfortunately, the available data are not such that the effect of varying any one parameter can be traced clearly through, without having to accept variations of several other parameters simultaneously, as, for instance, immersed tube length, outside chamber diameter and perhaps fluid flows and fluid properties. Hence it should not surprise that so far little headway was made to develop a generalised correlation. The most noteworthy attempt along this line was made by Vreedenberg in a recent paper.[18] It is reported that with the advent of new data original ideas for a generalised presentation[17] had to be revised. In the latest paper all internally heated or cooled fluidised beds are said to be represented by two separate correlations. One correlation is said to apply to the use of fine and light particles, where it is believed that viscous forces are predominant on the particles; the other correlation is recommended for coarser and heavier particles, where inertia forces are said to be active. Unfortunately, the distinction of what constitutes fine, light particles on the one hand and coarser and heavier particles on the other is not clearly discernible. As far as the final correlation is

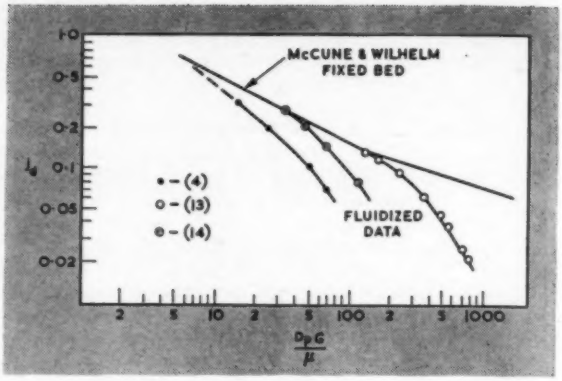

Fig. 6. Fixed bed and fluidised-bed mass transfer data.

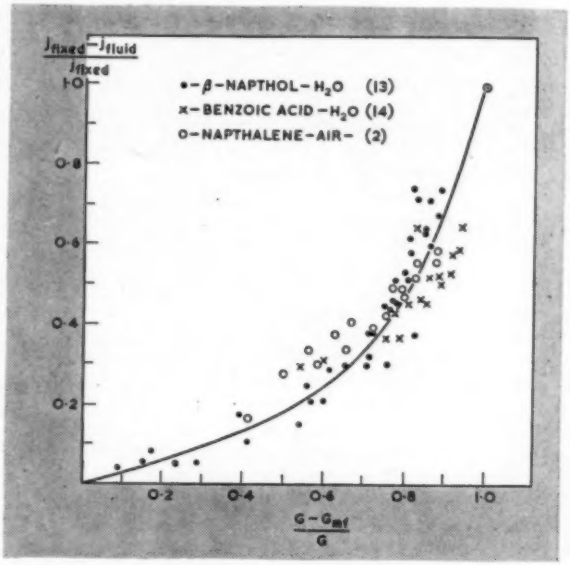

Fig. 7. Correlation of fluidised-bed particle—fluid mass transfer data.

concerned, it appears to be satisfactory to indicate order of magnitude in most instances. The correlations are based on the entire data repertoire, characterised by internal heat transfer elements. This considerable data segment includes studies in both the dense phase as well as the dilute phase, where voidages are of the order of 90% and more. In view of this, it is surprising to find that the final correlation includes no term that accounts for system density. One may well wonder whether a better correlation could not be achieved by the inclusion of such a term.

Industrial equipment of any appreciable diameter will invariably require a multitude of internal heat transfer elements. From the preceding discussion, it follows that much deliberation must be given the proper layout and diameter of these elements, so that the solids flow pattern remains intact, to assure proper fluid-solids contact for the reaction, as well as sufficiently high heat transfer rates. It is no understatement to say that the present data and correlations on hand offer in many instances only little more than an intelligent guide.

Heat Transfer between Particles and Fluid

The question of particle-fluid heat transfer is of fundamental importance to kineticists as well as engineers. However, because of the considerable difficulties that are involved in making the proper measurements in fluidised beds to evaluate these coefficients, comparatively little progress has been made. The few studies that have so far been made are summarised elsewhere.[12] Also given there are indications of a possible heat transfer mechanism.

Briefly stated, the chief difficulties involved with the experiments pertain to:

(1) establishing the proper solids temperature; and

(2) evaluating the surface area of the fluidised bed properly.

Heat quantity released or absorbed can usually be evaluated properly; however, with the temperature difference and possibly transfer area in doubt, it should not surprise to find that measurements for apparently quite similar systems may disagree by a logarithmic cycle or more.

Despite these difficulties, the probable data level of particle-fluid fluidised bed heat transfer has nevertheless been assessed.[12] Quite recently Richardson and Ayers[15] have reported the results of a study on this subject. Examination of one of their correlation lines indicate in the high flow range a gratifying measure of agreement with the earlier proposed correlation. In the lower flow range the new correlation runs higher. In consideration of this and the relatively conservative trend of the original data, it is felt that an adjustment of the original correlation may be in order at this time. Thus it is proposed to present fluidised-bed particle fluid data by the following correlation:

$$\frac{h\,D_p}{k} = 0.0193\left(\frac{D_p\,G}{\mu}\right)^{1.50} \qquad \ldots.(2)$$

The relative position of this correlation to the remainder of data is shown in Fig. 5. As further data become available, an additional revision might well result. The equation is believed to be valid for a Reynolds number range of about 6 to perhaps 60. Other limiting ranges are given in the paper by Richardson and Ayers[15] and the source of the original correlation.[12]

Particle-fluid Mass Transfer

There is indeed a dearth of data on this very important phase. Moreover, the few studies which have been reported[12] are not in the best agreement. The studies which were made with a liquid medium are, of course, more reliable than the gas-solid studies. This is so because with liquids the temperature of the solid may be more reliably evaluated; similarly, the effective particle surface area is more accurately determined, and, what is most important, relatively high beds can be employed without having the effluent leave the bed in a saturated condition.

Although it would have been a simple matter with liquid-solid systems to chart the true concentration gradient in the bed and thereby evaluate the true driving force, this was not done. Instead, validity of a logarithmic mean driving force was silently accepted as valid. Although this assumption is less in error with liquid-solid systems than it is with gas-solid systems, where back-mixing is indeed very profound[5, 6] the low course of the mass transfer data when compared to fixed bed data indicates that even in the liquid-solid system some back-mixing did exist. This conclusion is perhaps less justified for the minimum fluidisation region and its immediate neighbourhood; however, it is definitely indicated to be the case for elevated reduced mass velocities.

Just a few typical data pertaining to the major studies of liquid-solid systems is indicated in Fig. 6.[4, 13, 14] A full analysis is given elsewhere.[12] The fluidised-bed data are in agreement with the fixed-bed data only at the point of minimum fluidisation. As flow rates increase, the deviations increase. Of course, since a recalculation of the data and basing on the proper driving fore is impossible, the only practical way to align the data is indicated in Fig. 7. The correlation, comprising liquid as well as one gas system,[2] relates the ratio $\frac{j_{fixed}-j_{fluidized}}{j_{fixed}}$ to the ratio $\frac{G-G_{mf}}{G}$, which has been termed the bed-stirring ratio. This ratio is believed to be significant, since it relates the excess mass velocity over that required for the onset of fluidisation to the mass velocity under which the system operates. Thus the ratio should have a bearing on the solids transfer in the bed and thereby on the driving force that is active in the bed.

This correlation of mass transfer data is believed to mark a starting point for future work. Of course, the next problem is to ascertain the actual driving force that attends mass transfer. The correlation given in Fig. 7 was, of course, developed from small-scale data. Since it is dependent on solids flow patterns, which in turn are affected by the design and dimensions of equipment, it is borne in mind that it must be used with prudence for purposes of scale-up.

REFERENCES

[1] Baerg, A., Klassen, J., and Gishler, P. E. *Can. J. Research*, 1950, **F 28**, 287-307.
[2] Chu, J. C., Kalil, J., and Wetteroth, W. A. *Chem. Eng. Progress*, 1953, **49**, 141-9.
[3] Dow, W. M., and Jakob, M. *Chem. Eng. Progress*, 1951, **47**, 637-48.
[4] Evans, G. C., and Gerald, C. F. *Chem. Eng. Progress*, 1953, **49**, 135.
[5] Gilliland, E. R., and Mason, E. A. *Ind. Eng. Chem.*, 1949, **41**, 1191.
[6] Gilliland, E. R., and Mason, E. A. *Ind. Eng. Chem.*, 1952, **44**, 218.
[7] Heerden, C. van, Nobel, A. P. P., and Krevelen, D. W. van. *Chem. Eng. Science*, 1951, **1** (2), 51-66.
[8] Heerden, C. van, Nobel, A. P. P., and Krevelen, D. W. van. *Ind. & Eng. Chem.*, 1953, **45**, 1237-42.
[9] Leva, M., Weintraub, M., and Grummer, M. *Chem. Eng. Progress*, 1949, **45**, 563-72.
[10] Leva, M. "General Discussion on Heat Transfer", Sec. V, Inst. of Mech. Engrs., London, 1951.
[11] Leva, M., and Grummer, M. *Chem. Eng. Progress*, 1952, **48**, 307-13.
[12] Leva, M. "Fluidization", McGraw-Hill Book Co., New York, 1959.
[13] McCune, L. K., and Wilhelm, R. H. *Ind. Eng. Chem.*, 1949, **41**, 1124.
[14] Ohtake, T. "Review of Fluidisation Literature", by T. Shirai, Tokyo Inst. of Technology, Tokyo, 1954.
[15] Richardson, J. F., and Ayers, P. *Trans. Inst., Chem. Eng.* (*London*), 1960, **37**, 314.
[16] Toomey, R. D., and Johnstone, H. F. *Chem. Eng. Progress Symposium Series 5*. 1953, **49**, 51-63.
[17] Vreedenberg, H. A. *Chem. Eng. Sci.*, 1958, **9**, 52.
[18] Vreedenberg, H. A. *Chem. Eng. Sci.*, 1960, **11**, 274-85.
[19] Wicke, E., and Fetting, F. *Chemie Ing. Tecknik*, 1954, **26** (6), 301-9.

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A NEW CYCLONIC-FILM EVAPORATOR

Details of a successful evaporator designed to provide high heat transfer rates with reduced surface fouling

ACCORDING to recent Russian experience in the evaporation of alkali-aluminate solutions in alumina-processing plants, a number of disadvantages in the design of evaporators at present in use in that country have become apparent.[1] These are:

(1) low coefficients of heat transfer;
(2) heating surfaces become quickly encrusted with soda and aluminosilicate deposits;
(3) appreciable entrainment occurs, leading to a loss of the aluminate solution and pollution of the condensate.

The first two of these short-comings are attributed to the low solution velocity, usually not more than 1-1.3 mm/sec.

One possible solution is to employ forced-circulation evaporators, but these require high-capacity pumps, considerable expenditure of energy, and large separators, factors which detract from the economics of alumina production.

In seeking a more economical and at the same time more effective evaporator, Kuz'min carried out investigations upon a small single-tube cyclonic-film evaporator (Fig. 1) with a heating surface of 1 m², the tube being 7 m in length and 57 × 3.5 mm in diameter. A feature of the apparatus is the tangential input of the solution into the upper part of the tube and its high-speed filmwise downflow along the inside of the tube.

This equipment was the forerunner of an industrial cyclonic-film evaporator with a heating surface of 700 m² (Fig. 2), the operation and performance of which Kuz'min describes. The solution is fed by the circulating pump at a speed of approximately 1 m/sec. into the upper header. From here the solution is introduced into the evaporator tubes through the tangential inlets (which are made in the form of caps fixed over the end of each tube), and under the influence of its own weight it flows down the interior surface of the tubes in a thin layer. The lower chamber is filled with a solution to approx. ¾-⅞ of its height.

Due to the small thickness of the solution layer, the high free surface of evaporation and the fact that the pressure on the free surface of the film is lower than on the side of the film adjacent to the tube wall, the secondary vapour is given off in small bubbles and at a greater rate than with other types of evaporator. In the tube the solution and the vapour move in separate streams, and do not mix. The large vaporisation surface and the fact that the interior of the tubes is not filled with the solution, thereby providing separation space, makes for considerable spray removal and eliminates the need for an additional separating device. The downflow of the vapour along the tubes enables the speed of the solution to be increased and promotes stable filmwise flow of the liquid.

The weak solution is added through the intake pipe of the circulating pump, while the evaporated solution is led off through the lower connection of the solution receiver. A branch in the lower compartment is fitted for the exit of

TABLE I—Results of Trials of New Type of Evaporator Obtained on Evaporation of Industrial Alkali-aluminate Solution

Effect (by concentration)	Temp. in °C		Test Data												
	Heating steam	Boiling solution	Temperature difference	Time of uninterrupted operation in hr	Boundary value of K in kcal/m² hr °C	Mean value of K for time of test in kcal/m² hr °C	Specific heat load in kcal/m² hr °C	Composition of evaporated aluminate solutions						Calculated date	
								Na_2O gen.	Na_2O carb.	Na_2O caust.	Al_2O_3	SiO_2	α caust	Film speed in m/sec.	Film thickness in mm
1st	149.7	138.5	7.0	8.2	3900–3700	3800	$44.5 \cdot 10^3$	164.2	17.2	147.2	66.7	0.48	3.62	3.6	2.50
2nd	136.4	124.1	8.3	10.0	3650–3580	3600	$44.0 \cdot 10^3$	198.2	18.8	179.4	72.0	0.58	4.08	3.6	2.45
3rd	123.9	111.0	11.0	8.0	3100–3000	3050	$39.5 \cdot 10^3$	241.9	21.4	219.6	92.4	0.8	3.9	3.6	2.45
4th	137	117	17.5	8.0*	2850–2080	2450	$49.0 \cdot 10^3$	339.4	23.9	315.5	129.8	0.9	3.99	3.5	2.40

* For 21 hr operation (under identical conditions) the heat-transfer coefficient K fell from 2850 to 1690 kcal/m²/hr/°C. At a heating steam temperature of 150° and solution boiling temperature of 132.2°, the coefficient was reduced in 8 hr from 2700 to 1850 kcal/m²/hr/°C.

vapour and the steam supply and condensate removal are effected in the usual way.

Trials with this evaporator were carried out upon industrial alkali-aluminate solutions of differing concentrations of high soda and organic additive content. The results of the tests are given in Table I. Evidently the new design provides, when evaporating the industrial solution, high heat-exchange coefficients in the effect system in which it was used. The final concentration of the evaporated solution was 300 g/l.

For comparison we give below the heat-transfer coefficients obtained during tests in a four-effect reverse-flow industrial plant with a heating surface of 2000 m² yielding water evaporation of approximately 63 tons per hour.

Effect	*Heat-transfer coefficients*
1st	1450 kcal/m² hr 1°C
2nd	1100
3rd	950
4th	550

With this installation some of the tubes of the calandrias were destroyed by erosion after 56 days of operation.

It is estimated from the results of Table I that the new type of evaporators in a four-stage assembly of identical surface will evaporate about 190 tons of water per hour, i.e., its evaporative capacity will be 3 times greater, and compared with other forced circulation evaporators, apart from its heat-transfer superiority its designers consider that it has a number of other advantages. These are: capacity of circulating pump 2-3 times lower; expenditure of electrical power 1.5-3 times less. Thus, a forced-circulation evaporator with tubes 38 × 3 mm in diameter, 7 m long and with a heating surface of 700 m², will for solution velocity of 3.6 m/sec. require for each effect a circulating pump with a capacity of 7850 m³/h at a pressure of 6.9 m water gauge and a 275-kW electric motor. For a cyclonic-film evaporator with the same heating surface, and tubes 57 × 3.5 mm in diam., a pump with a capacity of 4000 m³/h at a pressure of 9.5-10 m water gauge and a 185-kW electric motor will be required.

Finally, in the manufacture of the new evaporator less metal is needed, its total weight being 2-2.5 times less.

TABLE II—Operating Conditions in a Four-effect Parallel Evaporator Plant

Variable	Effect			
	1st	2nd	3rd	4th
Temperature in °C				
of heating steam	155.0	136.5	116.1	92.2
of boiling of the solution	143.6	124.6	103.2	76.4
of vapour	136.5	116.1	92.2	60.0
of condensate	149.3	130.5	109.6	84.3
Useful temperature difference in °C	11.4	11.9	12.9	15.6
Depression in °C	7.1	8.5	11.0	16.6
Concentration of NaO in g/l				
on input	125	147	177	222
on output	147	177	222	300
Specific wt. of solution at 20° in kg/l	1.246	1.288	1.350	1.433

Table II shows that a parallel-flow scheme excludes the boiler tubes being affected by a solution that has at the same time a high temperature and concentration. Thus in the first stage the solution has a high temperature but its concentration is low. On the other hand, in the fourth stage the concentration of the solution is high but its temperature low.

Parallel flow evaporation makes possible the elimination of the rapid failure of the evaporator heating surface (in 56 days) observed in reverse flow units. Calculations made on the basis of the test data on the speed of corrosion of tubes by alkali-aluminate solutions showed that in a parallel-flow scheme the tubes of the third effect will be destroyed

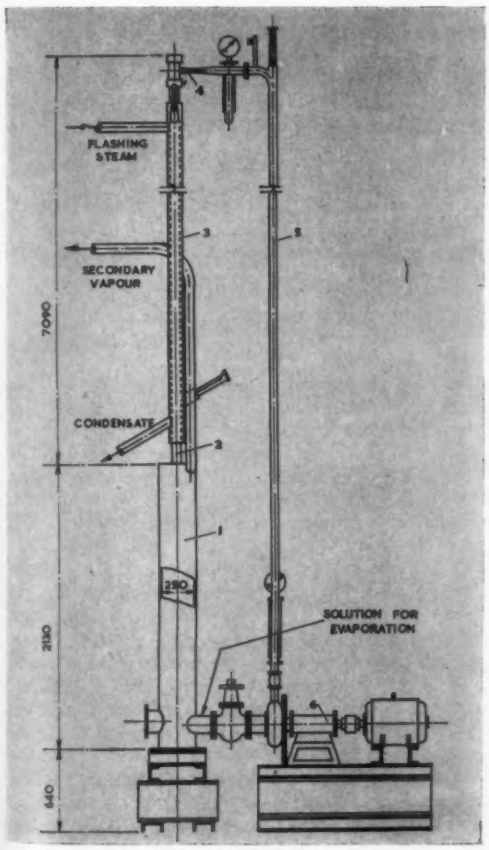
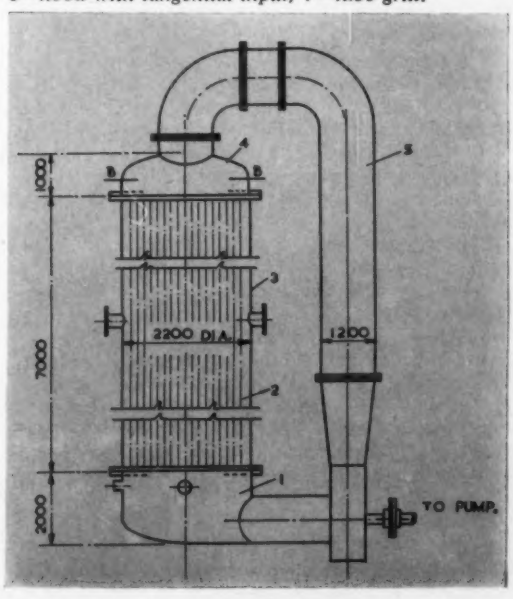


Fig. 1. Trial cyclonic-film evaporator with heating surface 1 m². 1—solution chamber; 2—boiler tube; 3—steam sleeve; 4—tangential input; 5—uplift tube; 6—NP-1 pump.

Fig. 2. Industrial cyclonic-film evaporator with forced circulation heating surface 700 m². 1—lower solution chamber; 2—boiler tubes; 3—heating chamber; 4—upper solution chamber; 5—uplift solution tube; 6—hood with tangential input; 7—tube grill.



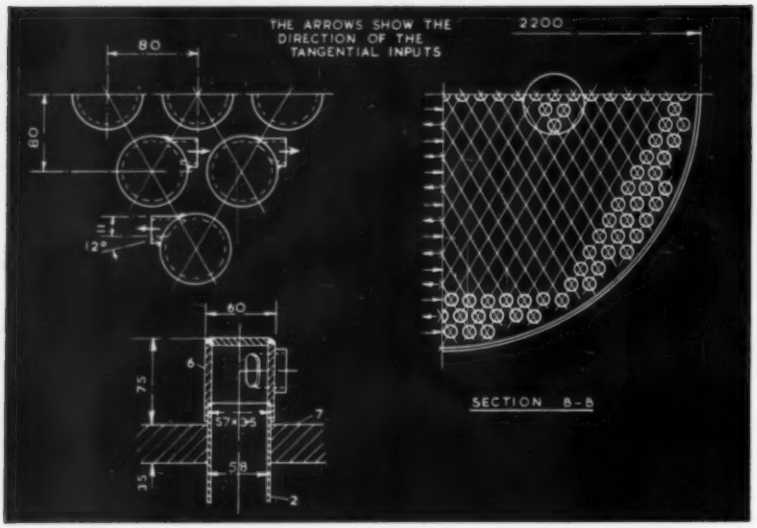


Fig. 3. Tube sheet layout with details of solution swirl-caps fitted to evaporator tubes. (Dimensions in mm.)

more rapidly than those of the remaining effect. Their operating life is limited to 4-4.5 years.

It is considered impossible to improve the parallel-flow plants at present in use, because of the considerable encrustation of the tubes by aluminosilicate and soda. Use of the new design of evaporator, which combines a high solution speed with a pronounced directional effect aided by the action of gravity, offers good prospects of a decrease in the rate of tube fouling. The data presented in Table I show that in the fourth effect, through the deposition of soda, the coefficient of heat transfer drops in 8 hr from 2850 to 2080 and in 21 hr to 1690 kcal/m² hr °C. Although the tempo of this decrease is at a lesser rate than in existing Russian evaporators, the soda deposition nevertheless prevents the adoption of the usual form of parallel flow system.

In order to overcome soda encrustation and to produce economical parallel four- and five-effect plants, Kuz'min proposes a new version of the uniflow scheme, its underlying principle being that after 8-10 hr of operation the direction of the vapour and the solution flow change simultaneously. By this means the fourth stage becomes the first and vice versa.

The results of Table I show for the industrial solution that the first, second and third effects do not exhibit signs of aluminosilicate or soda encrustation after 8 hr; but in the fourth effect, through soda deposition, the mean coefficient of heat transfer has a value of approximately 2500 kcal/m² hr °C after the same period, i.e., 4.35 times more than in existing evaporators (when working *in vacuo* the decrease is 12-16%).

The suggested method of operation would remove the need for frequent removal of soda from the heat-transfer surfaces, an operation which reduces the productivity of the equipment.

Further tests showed that when the fourth effect switches from evaporating a strong industrial solution to a weak solution (to the solution from the first stage), soda is flushed out in 4-6 min. and the apparatus operates with a heat-transfer coefficient equal to that of the first effect. The author believes that by employing evaporators of the new design together with the proposed parallel flow multi-effect system the periodic removal of the aluminosilicate by sulphuric acid will be unnecessary. Kuz'min points out, however, that there is some doubt about the second and third stages. Aluminosilicate accumulation in the first stage is improbable. Thus, judging from the results of the brief tests given in Table I, aluminosilicate is not precipitated on the first-effect tubes after 8 hr of operation. He considers that it is precipitated, but in a small quantity; but, in the non-flushing system, after the change-over, the strong solution will remove the aluminosilicate automatically from the first-effect tubes, since the latter is easily soluble in the strong solution. Thus, the construction of a parallel-flow, multi-effect, non-flushing assembly from evaporators of differing design is feasible: the first and fourth effects would be evaporators of the natural-circulation type, whereas the second and third, since they are more vulnerable to aluminosilicate encrustation, would be cyclonic-film or other evaporators with a high solution speed. The problem of the proposed parallel multi-effect scheme is a separate one which Kuz'min discusses in order to encourage its fuller investigation.

REFERENCE

[1] Kuz min, N. P. *Khim. Mash.*, 1960, **2**, 1-4.

Overseas Orders for Evaporators

POST-WAR experience has shown that the most potent weapon in penetrating and holding overseas markets is a technical advantage in the product provided that its price is reasonably competitive.

In the field of condensing of potable and other liquids the British A.P.V. Co. Ltd. is obtaining remarkable success with its plate evaporator. Greatly increased attention is being given throughout the world to the condensing of liquids at the point of production in order to reduce transport and packaging costs. This applies particularly to fruit juices, milk and milk products, although many other liquids are treated in this way.

The A.P.V. plate evaporator employs an entirely new principle of construction and operation which results in reduced first and installation costs, simpler operation and a marked improvement in the quality of the product. These advantages have tipped the scales in most overseas markets, including the highly competitive U.S.A. market. In the short time that this evaporator has been available, orders have been received to date for over fifty complete installations for overseas countries in addition to the many in Great Britain. The countries buying them are the U.S.A., Russia, France, Canada, Australia, New Zealand, India, Pakistan, South Africa, Kenya, Rhodesia, Ireland, British Honduras, Argentina, Brazil, Switzerland and Austria.

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COMMINUTION THEORY AND PRACTICE

PART II

The present limited theories offer a tentative means of grinding equipment selection

by D. KELLEHER, M.Sc., A.M.I.Chem.E.

WHEN the relative power requirements required for the reduction of different materials in a given machine are being evaluated, it is more usual to use Equations (1) and (2) in the following forms.[21]

$$E = C'F(S'_w - S_w) \qquad \ldots.(1a)$$

$$\text{and } E = C'F\left(\frac{1}{d} - \frac{1}{D}\right) \qquad \ldots.(2a)$$

As in the case of the constant C in Equations (1) and (2), the constant C' does not have precisely the same significance in Equations (1a) and (2a); i.e., C' in Equation (1a) includes the constant $K'(= f/k)$ whereas C' in Equation (2a) includes the constant $K(= f/\delta k)$. To bring the constant C' to the same significance in both equations, (2a) should be written:

$$E = \frac{C'}{\delta} \cdot F\left(\frac{1}{d} - \frac{1}{D}\right) \qquad \ldots.(2b)$$

The symbol F denotes the compressive strength (or crushing resistance) of the material undergoing size reduction, which has already been shown to be directly related to its scratch hardness number.

It has been found expedient in the evaluation of the power for size reduction of materials to take a given material as standard and to determine the power required to reduce it from a given feed size to a given product size or to enlarge its specific surface by a given amount. The power required to reduce the size of another material can then be circulated directly on the basis of relative compressive strengths and proportionate degrees of size reduction. A convenient standard material is limestone, which has a compressive strength of 10,000 psi.

Example (2) (*A.M.I.Chem.E. Exam.*, 1930)

A crushing machine in reducing limestone having a crushing test figure of 10,000 psi from ¼-in.-diameter average size to $\frac{1}{300}$ in. diameter requires 12 hp. The same machine is then used to crush dolomite, having a crushing test figure of 15,000 psi, from a ¼-in. average size to a final product which consists of 20% with an average diameter of $\frac{1}{100}$ in., 60% with an average diameter of $\frac{1}{200}$ and the remainder with an average diameter of $\frac{1}{300}$ in. Estimate the hp required to drive the crusher in this case, assuming equal output.
(Density of limestone = 2.65 g/cc. Density of dolomite = 2.74 g/cc)

Solution

Use is made of Equation (2b).

For limestone

$$12 = C' \cdot \frac{1}{2.8} \cdot 10{,}000\ (300 - 4)$$

$$C' = \frac{1.2 \times 2.8 \times 10'}{1 \times 10^4 \times 2.96 \times 10^3} = 1.135 \times 10^{-5}$$

Size analysis of dolomite

mean size d (in.)	Δw (%)	$\Delta w/d_x$
$\frac{1}{100}$	20	2,000
$\frac{1}{200}$	60	12,000
$\frac{1}{300}$	20	6,000
	$W = 100$	$\sum \frac{\Delta w}{d_x} = 20{,}000$

$$\frac{1}{d} = 200$$

Hence for dolomite by Equation (2b)

$$E = 1.135 \times \frac{1}{2.9} \times 15{,}000\ (200 - 4)$$

$$= \frac{1.135 \times 10^{-5}}{2.9} \times 1.5 \times 10^4 \times 1.96 \times 10^2$$

$$= 11.5 \text{ hp.}$$

In applying RITTINGER's Law in the two examples given, it has been assumed in effect that if X' is the size of sieve aperture which passes a fraction $\triangle W$ of a total weight of material W and if X'' is the size of sieve aperture which just retains the same fraction, then the mean size of particle (d_x) in a fraction $\triangle W$ is given by:

$$d_x = \frac{X' + X'}{2}$$

This procedure obviously ignores the large variation in size which may exist between X' and X''. This will not affect the results greatly if the corresponding $\triangle W$ is not too large, but the intrinsic error in relying on a series of average sizes $d_1, d_2, \ldots d_n$ to evaluate a final average size d for W as a whole can be avoided by GATES' graphical method[22] of evaluating specific surfaces from undersize distribution data.

Thus for any weight $\triangle W$ comprising a small portion of a cumulative weight W (denoted by the ordinate in an undersize distribution curve (c.f., Fig. 9) we may write:

$$\text{Total surface per weight } \triangle W = \frac{f}{k\,\delta} \cdot \frac{\triangle W}{d_x} = K\frac{\triangle W}{d_x}$$

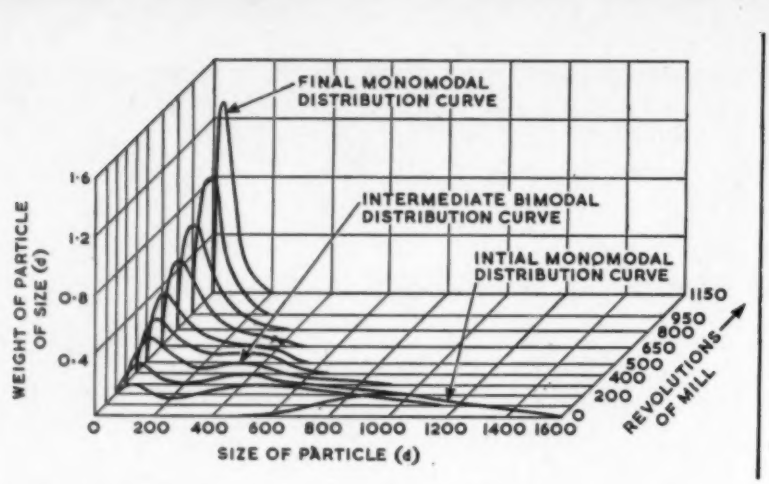

Fig. 9. Variation of size distribution with progress of grinding. (Courtesy Institution of Mechanical Engineers.)

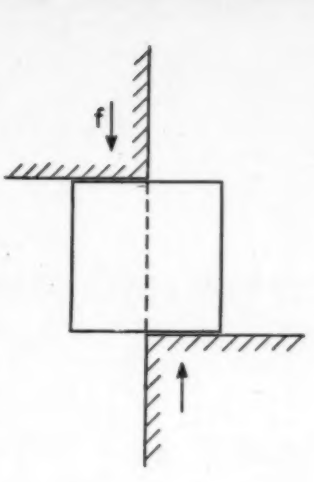

Fig. 10. Cube of homogeneous material under deforming stress.

Hence the total surface per weight $W = K\sum_{0}^{W}\frac{\triangle W}{d_x} = K\int_{0}^{W}\frac{dW}{d_x}$.

The value of $\int_{0}^{W}\frac{dW}{d_x}$ may be obtained by plotting d_x (the abscissa on the undersize distribution curve) in reciprocal as ordinate against the corresponding per cent undersize (i.e., the ordinate on the undersize distribution curve) as abscissa. The area under such a curve is then equal to $\int_{0}^{W}\frac{dW}{d_x}$. If this area is representative of the product, then the corresponding area for the feed is $\int_{0}^{W}\frac{dW}{D_x}$ where D_x represents the particle size of the sieve particles. The difference or $K\left(\int_{0}^{W}\frac{dW}{d_x} - \int_{0}^{w}\frac{dW}{D_x}\right)$ then represents the increase in surface area obtained by grinding and hence the power represented are obtained from:

$$E = C\left(\int_{0}^{W}\frac{dW}{d_x} - \int_{0}^{w}\frac{dW}{D_x}\right) \qquad \ldots.(7)$$

where the constant C includes the shape factor K as before.

Example (3) (*A.M.I.Chem.E. Exam.*, 1950)

Lumps of limestone of average size 1½ in. were crushed in a mill and gave a product with the following screen analysis.

	%
−0.6 in. + 0.5 in.	0.5
−0.5 in. + 0.4 in.	8.5
−0.4 in. + 0.3 in.	45.0
−0.3 in. + 0.2 in.	20.0
−0.2 in. + 0.1 in.	18.0
−0.1 in.	8.0

The energy consumption was 8 hph per ton of material crushed. Calculate the power required to crush the same material at the same rate from a feed having a mean size of 1 in. to a product with a mean size of 0.04 in.

Solution

The material retained on any screen is the oversize or + material; that passing the screen is the undersize or − material. Thus for the product in the first grinding operation.

% undersize	% size (d_x) (in.)	$\frac{1}{d_x}$
100	0.6	1.67
99.5	0.5	2.0
91.0	0.4	2.5
46	0.3	3.3
26	0.2	5.0
8	0.1	10.0

The % undersize is plotted against $1/d_x$ and the area under the curve (by SIMPSON'S Rule) corresponds to 455 units, which is a measure of the surface area of the product corresponding to 100 units of weight. A corresponding measure of the surface area of the feed of mean size 1.5 in. $= \frac{100}{1.5} = 66.7$ Hence, applying RITTINGER'S Equation in the following form

$$E = C\left(\int_{0}^{W}\frac{dW}{d_x} - \frac{W}{D}\right)$$

$$8 = C(455 - 66.7)$$

$$\therefore C = \frac{8}{388.3}$$

Hence energy in second operation is obtained:

$$E = \frac{8}{388.3}\left(\frac{100}{0.4} - \frac{100}{1}\right) = \frac{800}{388.3}\ (25-1)$$

$$E = 52.2 \text{ hp}$$

Critique of Rittinger's Hypothesis

BOND[23] has pointed out that RITTINGER'S Law has only a limited application to industrial crushing and grinding installations, and that strict concordance with RITTINGER'S Law has only been obtained when experiments have been carried out either on:

(a) feeds of screeded particles passing one sieve size; or

(b) scalped feeds with the fines removed.

LOWRIE-FAIRS,[24] however, found in experiments conducted on laboratory-scale machines, which included an impact crusher, a batch ball mill, swing hammer mills with screen discharge and a type of fluid energy mill with integral classifier, that a linear relationship existed between net energy input and area of new surface produced (measured by a permeability method) in the case of barytes, limestone and anhydrite regardless of whether or not the fines or oversize had been removed in the feed. The feeds were, in fact, either closely graded material or else the untreated products of first- or second-stage grinding. Deviations took place only at the later stages of grinding in some instances of ball mill grinding and were attributed to the onset of packed crushing, i.e., the fines produced

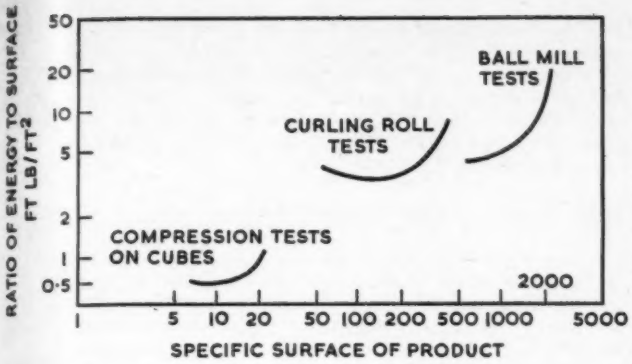

Fig. 11. Variation of energy to surface ratio with fineness of product (South Wales coal).

filled the voids between the larger particles, cushioning them and causing a pelleting effect and therefore resulting in a loss of grinding efficiency. The other mills with integral chambers achieved much greater product fineness but maintained a constant energy/surface ratio. LOWRIE-FAIRS termed the point of departure from linearity as the "limit of grinding at maximum efficiency". His net energy input, however, was not the total energy for grinding of RITTINGER'S hypothesis, but the difference between the energy expended when a machine was running under load and when running empty.* The implication is, nevertheless, that the law may be intrinsically valid for certain types of fine grinding operations with brittle materials. The relationship was found also to hold for rock salt, which is subject to plastic deformation, but the performance ratios of the mills with this material differed from those obtained for limestone, barytes and anhydrite as set out in Table IV. Thus the batch ball mill, one of the most efficient for brittle materials, was the least efficient with rock salt.

Another practical objection to RITTINGER'S LAW is that it assumes in effect, as MARTIN[25] pointed out, that there is a constant molecular attraction holding together the particles composing any crystalline substance; it implies, moreover, that in dividing the particles and in producing fresh surface, work is being done against a constant force analogous to the constant force as, for example, involved in the distension of the surface of a soap bubble film. LOWRIE-FAIRS' experiments would lend support to this hypothesis. There is, however, evidence to the contrary which shows that with a given material the energy required to produce unit area of a new surface increases as the particle sizes are progressively reduced. HEYWOOD states that this could be due to changes in the properties of a material with reduction in particle size, and cites, in example, the predominance of internal fission in larger particles as against smaller particles. The results obtained in some experiments with South Wales Coal have been reported by HEYWOOD.[26] These show (Fig. 11) that the early stages of grinding in a given mill are more efficient and that the minimum value for the energy/surface ratio increases with intensity of comminution. HEYWOOD, however, does not rule out the possibility that the mechanical forces in each machine might have been less effectively utilised as grinding progressed (cf. packed crushing effect in LOWRIE-FAIRS' experiments).

MARTIN[25] has subjected RITTINGER'S hypothesis to a more severe criticism on theoretical grounds. Thus if the work involved in volatilising a given material (which may be regarded as being analogous to the grinding of the material to "particles" of molecular dimensions) is compared with practical grinding tests, it is found that the energy required in grinding to produce 1 sq. ft of new surface is much greater than that required to produce 1 sq. ft of new surface by volatilisation.

To take an example, consider the work involved in volatilising 1 lb. of quartz sand. The latent heat of volatilisation of silica is 1765 Btu/lb., and hence the work done to gasify 1 lb. of silica is $1765 \times 778 = 1.4 \times 10^6$ ft lb., where 778 = Joules equivalent. The surface area corresponding to 1 lb. of silica materials is 3.8×10^6 sq. ft. Hence the work done to increase the surface by 1 sq. ft is $(1.4 \times 10^6)/(38 \times 10^6) = 1/27$ ft lb. In a practical test with a ball mill MARTIN found that the work required to enlarge the surface of a quartz sand feed by 1 sq. ft was 60 ft lb., from which he concluded that the absolute efficiency of a modern tube mill would be of the order of only $100/(27 \times 60)$ or $\frac{1}{16}\%$.

It is noteworthy also that GAUDIN[27] attempted to modify RITTINGER'S Law by defining the efficiency of a comminu-

* Measurement of energy input was by means of a kWh meter or else by ammeter readings and the corresponding stator line current/output horsepower curves for the motors used. The difference between the power usages for the mills running under load and light divided by the throughput (t/hr) gave the net energy consumption in kWh/hr.

TABLE IV—Comparison of Mill Efficiencies***

Mill	*Average Energy/unit new surface (ergs/cm)²*			*Performance Ratio*		
	Limestone	*Barytes*	*Anhydrite*	*Limestone*	*Barytes*	*Anhydrite*
Unit impact Crusher	9.96×10^4	6.84×10^4	6.33×10^4	1	1	1
Batch ball mill†	10.2×10^4	6.43×10^4	6.42×10^4	0.98	1.06	0.99
Swing hammer						
Screen discharge mills						
(a) with close clearances	9.25×10^4	6.84×10^4	6.06×10^4	1.08	1.00	1.05
(b) with fine clearances	1.95×10^5	1.02×10^5	1.02×10^5	0.51	0.67	0.62
Attrition mill with static chamber	2.77×10^5	1.89×10^5	1.71×10^5	0.36	0.36	0.37

* The slopes of the lines relating energy to surface are an inverse measure of the relative efficiencies of the mills. The performance ratio is obtained for each mill for each material by taking the energy/surface ratio for the unit impact crusher as unity.

† Laboratory-scale drop weight apparatus.

TABLE VI—Average Work Indices

Material	No. of Tests	Average Specific Gravity 'S'	Average Work Index 'Wi'
All materials tested	1242	—	14.39
Barite	7	4.50	4.73
Bauxite	4	2.20	8.78
Cement clinker	16	3.15	13.45
Clay	7	2.51	6.30
Coal	2	1.4	13.00
Coke	8	1.31	15.13
Glass	4	2.58	12.31
Granite	37	2.66	15.13
Hæmatite	61	3.53	12.84
Hæmatite—specular	3	3.28	13.84
Lead ore	10	3.35	11.90
Limestone	79	2.66	12.74
Phosphate rock	17	2.74	9.92
Silica sand	5	2.67	14.10
Silicon carbide	3	2.75	25.87
Zinc ore	12	3.64	11.56

For illustrative purposes only, as individual variations of work indices of materials in any one classification may be quite large, e.g.:

Silica sand, Ottawa, Illinois .. .. Wi = 19.6
Silica sand, Boise, Idaho .. .. Wi = 10.8

TABLE IX—Part of Table of Rod Mill Sizes and Horsepower Requirements

Maker's Mill Size No.	Rvd Charge wt. (lb.)	Rpm	Motor hp
710	60,000	20.8	250
712	72,000	20.8	250
810	78,000	18.2	300
812	94,000	18.2	350
912	120,000	16.5	450
9½12	134,000	15.2	500
" 12	167,000	14.5	700

TABLE XI—Calculations of Energy Inputs for Successive Theoretical Reductions of Cubes (Holmes' Law Derivation)

Reduction Ratio	Size of Initial Particle	Energy Input for Given Reduction Ratio
$2 = 2^1$	D	$kD^{1-r} \cdot 3\ D^2$
$4 = 2^2$	$\frac{D}{2}$	$8k\left(\frac{D}{2}\right)^{1-r} \cdot 3\left(\frac{D}{2}\right)^2$
$8 = 2^3$	$\frac{D}{4}$	$64k\left(\frac{D}{4}\right)^{1-r} \cdot 3\left(\frac{D}{4}\right)^2$
$16 = 2^4$	$\frac{D}{8}$	$512k\left(\frac{D}{8}\right)^{1-r} \cdot 3\left(\frac{D}{8}\right)^2$
2^z	$\frac{D}{2^{z-1}}$	$8^{z-1}\,k\left(\frac{D}{2^{z-1}}\right)^{1-r} \cdot 3\left(\frac{D}{2^{z-1}}\right)^2$

tion operation as "the ratio of the surface energy produced to the kinetic energy expended", but nevertheless found that 99% of the work input was wasted in practical tests.

BOND[23] has suggested that the low mechanical efficiencies are apparently obtained, because neither RITTINGER'S nor GAUDIN'S theories account for the fact that the breaking of rock involves primarily its deformation beyond the elastic limit, causing fatigue failure with a release of the energy of resilience as heat. This energy is therefore not recoverable in the product. Thus the assumption that the surface energy of the material after breakage is increased by the amount of useful work applied during breakage is invalid, and this fact accounts for the 99% loss found in GAUDIN'S experiments. The energy loss has, in fact, been determined by FAHRENWALD *et al.*[28] by immersion of a small ball mill in a calorimeter and measuring the temperature rise of the water flowing through, which showed conclusively that from 75 to 94% of the energy input to the machine was utilised in heating the water.

The Second Theory of Comminution

Kick's Law

The main criticism which can be directed to RITTINGER'S hypothesis is that it ignores the distance factor involved in particle deformation before breakage (i.e., work = force × distance).[23] This was accounted for in another theory proposed by KICK[29] in 1885 on the basis of a consideration of the deformation of bodies subjected to stresses within the elastic limit. In the following development of KICK'S theory due to HOLMES,[26] only the energy consumed in size reduction by elastic deformation is considered. It is assumed that the final yield point and elastic limit are close together as in most naturally-occurring rocks, and that work done in plastic deformation may be neglected. Energy consumed in producing new surface is also ignored, since, of the proportion of total energy input, that converted to surface energy is negligible ($<1\%$).

If a cube of perfectly annealed homogeneous isotropic material of side D be subjected to a deforming stress f acting in the plane shown dotted (Fig. 10), so that at any instant the deformation produced is S, then by HOOKE'S Law (stress is proportional to strain)

$$f = M \cdot \frac{S}{D} \text{ or } \frac{dS}{df} = \frac{D}{M} \qquad \ldots.(8)$$

where $\frac{S}{D}$ is the strain and M the modulus of elasticity. Hence the work done (P) per unit area of the dotted plane in producing an elastic deformation S is

$$P = \int_0^S f \cdot dS = \int_0^S f \cdot \frac{dS}{df} \cdot df = \int_0^S f \cdot \frac{D}{M} \cdot df$$

Since f is a function of S.

According to the assumptions made, the total energy for fracture (along the dotted plane) will for all practical purposes be represented by the stress (say) acting in the plane at the elastic limit. If B is the theoretical energy at this stage required to produce unit area of new surface, then

$$B = \frac{1}{2}\frac{D}{M}\int_0^{\varphi} f \cdot df = \frac{\varphi^2}{4M} \cdot D \qquad \ldots.(9)$$

The latter is essentially the primary statement of KICK'S Law, i.e., *"the energy* (E) *required for fracture is proportional to the weight or volume of the material"*, thus:

$$B = \frac{E}{2D^2} \text{ or } E = \left(\frac{\varphi^2}{2M}\right)D^3 \qquad \ldots.(10)$$

Again from Equation (10), the energy required to effect one fracture of area D^2 is

$$E = 2\,B\,D^2 = kD^3 = kD \cdot D^2$$

and the energy required to produce three fractures of area D^2 (or to produce eight cubes of side $D/2$) is given by

$$E = 3\,kD^3 = kD \cdot 3D^2$$

and the energy required to reduce these eight cubes of side $D/2$ to 64 cubes of side $D/4$ is given by

$$E = 8\,k\left(\frac{D}{2}\right) \cdot 3\left(\frac{D}{2}\right)^2 = 3\,kD^3$$

Table I was constructed on the above basis showing the effect of reducing a cube of side D into successively smaller cubes. Thus the reduction of a cube of volume D^3 to 512

cubic particles requires an energy input of 12 kD^3. If certain arbitrary values are assigned to D as follows, the energy input will be as shown.

D (in.)	Reduction Ratio	Total Volume of Material (cu. in.)	Energy Input
2	2^4	2^3	$12k\,(2)^3$
4	2^4	4^3	$12k\,(4)^3$
6	2^4	6^3	$12k\,(6)^3$

It is assumed that a change of shape from cubes to any other geometric configuration will not alter the form of the above relationship of variation of energy input with volume of particles for equal reduction ratios. Thus KICK's law as formulated by STADLER[21] states that *"the energy required for producing analogous changes of configuration in geometrically similar bodies of equal technological state varies as the volumes or weights of these bodies"*.

It is also apparent from Table V that, although the overall reduction ratio increases in geometrical progression, the overall energy input increases in arithmetical progression and thus

$$E = K \log R = K \log^{D/d} \qquad \ldots\ldots (11)$$

where D and d represent the initial and three final particle sizes respectively. Thus an alternative expression of KICK's Law is obtained; i.e., *the energy required to crush a given quantity of material to a desired fraction of the original particle size is constant regardless of the original size of feed.*

ANDREASON,[22] in studying the principle of similarity as applied to grinding processes, deduced that while the fineness (defined by the specific surface) increases according to a geometric series the energy consumption increases according to an arithmetic series, which he expressed in the formula

$$E = K \log \frac{S'_w}{S_w} \qquad \ldots\ldots (11a)$$

This means that specific surface measurements or, in effect, particle diameters computed for feed and product by means of Equations (4) and (5) can be used in conjunction with KICK's Law. The incompatibility of KICK's and RITTINGER's Laws is illustrated by the following example.

Example (4) (*A.M.I.Chem.E. Exam.*, 1935)

A coal grinding unit required 5 kWh per ton in reducing ¼-in. lumps to a product of the following screen analysis:

52 mesh (aperture 0.0116 in.) 100%
72 mesh (aperture 0.0083 in.) 70%
85 mesh (aperture 0.0070 in.) 20%
100 mesh (aperture 0.0060 in.) 50%

It is required to produce a product of the following screen analysis from the same feed.

150 mesh (aperture 0.0041 in.) 100%
170 mesh (aperture 0.0035 in.) 50%
200 mesh (aperture 0.0030 in.) 20%
240 mesh (aperture 0.0026 in.) 50%

Estimate approximately the power required per ton by (a) RITTINGER's Law; (b) KICK's Law.

Solution

(a) RITTINGER's Law

Sieve Size (in.) Through	Sieve Size (in.) On	Mean Size d_x(in.)	ΔW%	$\Delta \frac{W}{d_x}$
0.0116	0.0083	0.00995	30	3150
0.0083	0.0070	0.00765	50	6540
0.0070	0.0060	0.0065	15	2310
0.0060	0.000	0.0030	5	1665
			$\Sigma \Delta w = W = 100$	13,665

$$\therefore \frac{1}{d} = \frac{1}{W}\sum \frac{\Delta W}{d_x} = \frac{13{,}665}{100} = 136.65$$

by RITTINGER's Law

$$5 = C\,(136.65 - 2) \quad \therefore C = \frac{5}{134.65}$$

Sieve Size (in.) Through	Sieve Size (in.) On	Mean Size d_x(in.)	ΔW%	$\Delta \frac{W}{d_x}$
0.0041	0.0035	0.0038	50	13,750
0.0035	0.0030	0.00325	30	9240
0.0030	0.0026	0.0028	15	5360
0.0026	0.0000	0.0013	5	3850
			$\Sigma \Delta w = W = 100$	32,200

$$\therefore \frac{1}{d} = \frac{1}{W}\sum \frac{\Delta W}{d_x} = \frac{32{,}200}{100} = 322$$

$$\therefore E = \frac{S}{134.65}(322 - 2) = \frac{5 \times 320}{134.65} = 11.9$$

Hence energy requirements by RITTINGER's Law = 11.9 kWh

(b) KICK's Law

$$E = K \log D/d$$
$$5 = k \log 0.5 \times 136.65$$
$$k = \frac{5}{1.8346}$$

Hence $E = \frac{5}{1.8346} \log 0.5 \times 322$

$$= \frac{5}{1.8346} \times 2.2068 = 6$$

Hence energy by KICK's Law = 6 kWh.

Critique of Kick's Law

The above example shows that results obtained by KICK's Law are much less than those obtained by RITTINGER's Law. One reason for the discrepancy lies in the fact that KICK's Law fails to assign a sufficient proportion of energy to the reduction of finer particles. HOLMES[20] points out that a perfectly annealed homogeneous material whose resistance to reduction would not vary with particle size would obey KICK's Law. Rocks and minerals are usually inhomogeneous and are permeated with cracks, flaws and cleavage planes which are more predominant in the larger particles. Thus the resistance to reduction increases with decrease in particle size. KICK's Law has therefore been found unsuccessful in describing the behaviour of such materials.

On the other hand, RITTINGER's Law, by concentrating attention on the increase of surface area, which weight for weight is greater for finer particles, possibly fails to assign a sufficient proportion of the work to the reduction of larger particles and may, therefore, overestimate the power requirements.

The true results might therefore be regarded as lying somewhere between the energy requirements as determined by the application of both laws. It has been considered expedient in the past to regard RITTINGER's Law as being valid for fine grinding operations and KICK's Law for coarse-crushing operations. It would be more true to say, however, that RITTINGER's Law would apply to perfectly brittle material (cf. LOWRIE-FAIRS' experiments) and KICK's Law to perfectly elastic solids.

The Third Theory of Comminution

Bond's Law

According to HOLMES,[20] KICK's Law refers to the energy required to deform the particle to its elastic limit, whilst RITTINGER's Law refers to the energy absorbed in the rupture of physical and chemical bonds during fracture. BOND[23] in 1952 attempted to reconcile the postulates of KICK and RITTINGER into a simple law. BOND reasoned that, whilst the absorption of equally applied stress is proportional to the volume of material under consideration (cf. KICK's Law) in actual crushing operations, stresses are applied at protruding points rather than at regular surfaces. These points, therefore, crumble as pressure is applied until sufficient area is developed for the breakage of the particles

under non-uniform stresses. Breakage of the individual particles may be regarded as originating in crack tips on the surfaces of the particles, the formation of these crack tips being motivated by the concentration of surface stresses. Once a crack tip is formed, the surrounding strain energy in the stressed material immediately flows to it, rapidly extending it throughout the particle, splitting the particle and resulting in fracture. In this way, according to BOND, comminution processes involve the transformation of mechanical energy into strain energy before a crack tip forms, which is released as heat when the material breaks. The mechanical efficiency is the energy resulting in breakage divided by the total energy input.

On the basis of the crack tip hypothesis, BOND compounded the laws of KICK and RITTINGER into a single law. When stress is first applied, the strain energy of a particle may be regarded as being proportional to its volume, as KICK suggested, or proportional to D^3 where D is a dimension defining the size of the particle. However, with the formation of the first crack tip the strain energy flows to the surface, thus developing a breakage pattern, and at this point RITTINGER'S Law may be regarded as being valid, i.e., the strain energy of the particle is proportional to the surface area or proportional to D^2. Hence the proportional energy absorbed by a particle is a function of a dimension intermediate between D^2 and D^3 or a function of $\sqrt{D^2 \times D^3}$ or $D^{5/2}$. Now the number of particles of similar shape per unit volume of material is proportional to $1/D^3$, and thus the energy input to break a unit volume (or unit weight) is proportional to $D^{5/2}/D^3$ or to $1/\sqrt{D}$. Hence BOND'S Law, or the third theory of comminution, states that *the total energy useful in breakage which has been applied in one or more crushing or grinding operations, to a stated weight of homogeneous broken material, is inversely proportional to the square root of the diameter of the product particles.*

BOND, in applying his theory to comminution processes, defined the size of feed particle D (and product particle d) not as a mean particle size but as the size of sieve aperture through which 80% of the feed (or product) passes. This was based on SCHUHMAN'S observation[33] that if the logarithms of the per cent undersize by weight (W) of the particles are plotted against the logarithms of the sizes of the particles (X), where X is the size of sieve aperture, then the relationship is linear in the case of most materials, being expressed by the equation

$$\text{Log } W = m \log X + C \qquad \ldots (12)$$

The value of m is assumed to be the same for both feed and product and in most cases is equal to $1/\sqrt{2}$. The value of W of 80% was taken by BOND as the criterion in defining the feed ($X = D$) or product size ($X = d$), since this value was readily obtained without resort to tedious size analyses to determine the full size distribution, and, moreover, it was definite and reproducible. Thus the third theory of comminution, in effect, states that *the total work useful in breakage is inversely proportional to the square root of the diameter corresponding to the sieve aperture through which 80% of the product passes.*

If now E_f is taken to represent the work done in reducing a given feed to its given state of subdivision of particles before submitting it to further comminution, and if D represents the size of sieve aperture which 80% of the feed passes, then E_f is proportional to to $1/\sqrt{D}$. If the feed is now subjected to crushing or grinding and E_p represents the total energy involved in reducing the material to its final state of subdivision (i.e., E_p includes E_f in addition to further work done in crushing or grinding), with d representing the size of sieve aperture which 80% of the product passes, then E_p is proportional to $1/\sqrt{d}$. If now E represents the energy involved in transforming the feed to the product, then:

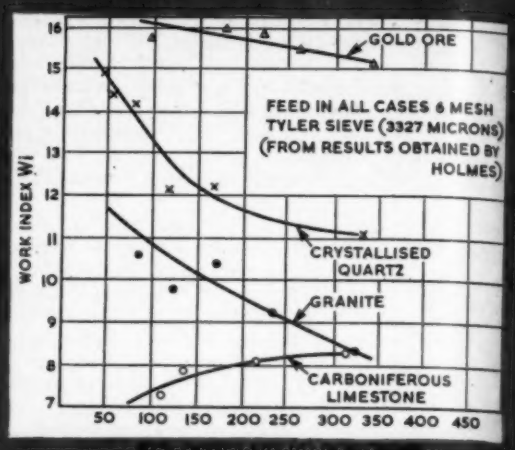

Fig. 12. Variation of work index with product fineness defined by the sieve size in microns through which 80% of the product passes.

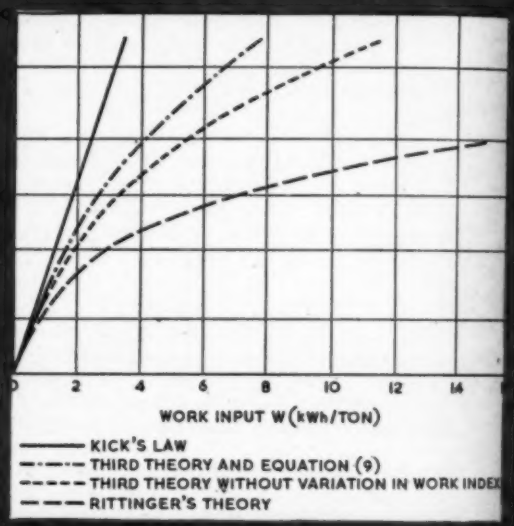
WORK INPUT W (kWh/TON)
KICK'S LAW
THIRD THEORY AND EQUATION (9)
THIRD THEORY WITHOUT VARIATION IN WORK INDEX
RITTINGER'S THEORY

Fig. 13. Graphical comparison of results obtained for power input in the size reduction of carboniferous limestone.

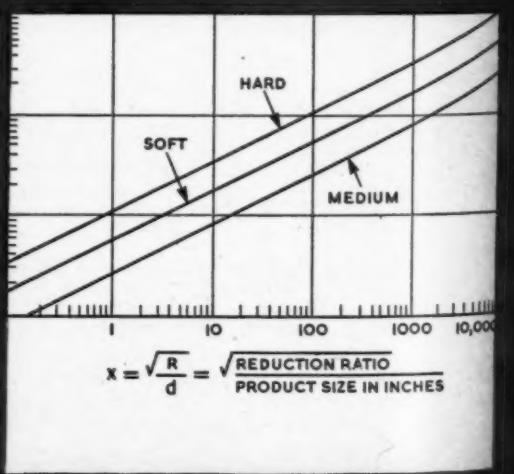

Fig. 14. Chart showing variation of work requirements with product size, reduction ratio and hardness.

TABLE V—Calculations of Energy Input for Successive Theoretical Size Reductions of Cubes (Kick's Law Evaluation)

Grinding Stage	Total Volume of Cubic Particles	Size of Individual Cubic Particles		Number of Particles		Reduction Ratio		Energy Input (E)	
		Initial	Final	Initially	Finally	Per Operation	Overall (R)	Per Operation	Overall
1	D^3	$D = \frac{D}{2}$	$\frac{D}{2} = \frac{D}{2^1}$	1	8	2	2^1	$kD \cdot 3D^2$	$3kD^2$
2	D^3	$\frac{D}{2} = \frac{D}{2^1}$	$\frac{D}{4} = \frac{D}{2^2}$	8	64	2	2^2	$8k\left(\frac{D}{2}\right) \cdot 3\left(\frac{D}{2}\right)^2$	$6kD3$
3	D^3	$\frac{D}{4} = \frac{D}{2^2}$	$\frac{D}{8} = \frac{D}{2^3}$	64	512	2	2^3	$64k\left(\frac{D}{4}\right) \cdot 3\left(\frac{D}{4}\right)^2$	$9kD3$
4	D^3	$\frac{D}{8} = \frac{D}{2^3}$	$\frac{D}{16} = \frac{D}{2^4}$	512	4096	2	2^4	$512k\left(\frac{D}{8}\right) \cdot 3\left(\frac{D}{8}\right)^2$	$12kD3$
x	D^3	$\frac{D}{2^{x-1}}$	$\frac{D}{2^x}$	8^{x-1}	8^x	2	2^x	$8^{x-1}\left(\frac{D}{2^{x-1}}\right) \cdot 3\left(\frac{D}{2^{x-1}}\right)^2$	$3xkD3$

TABLE VII

Operation Stage	Crushing	Rod Milling	Ball Milling
Circuit	Open-Dry	Open-Wet	Closed-Wet
Hours per day†	14	24	24
Tons per hour	143	83.4	83.4
Feed: 80% size or microns D	3 in.	$\frac{3}{4}$ in.	14 mesh
	76,200	19,050	1190
Product: 80% size or microns d	$\frac{3}{4}$ in.	14 mesh	100 mesh
	19,050	1190	149
Red. ratio: R = D/d	4.00	16.00	8.00
$Ei/E = 13.0/E$	27.6	4.60	1.89
KWh/ton = E	0.471	2.83	6.88
Hp or calculated power input = $E \times$ TPH $\times$ 1.34	90.3	316	769

TABLE VIII—Part of Table of Gyratory Crusher Sizes and Capacities
Courtesy Allis Chalmers

			Close side Setting of Discharge Opening										
One-Way Feed Size	Max¹ hp	Eccentric Throw (in.)	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
5483	75	$\frac{5}{8}$				80	82	83					
	100	$\frac{3}{4}$					103	105	107				
	125	$\frac{7}{8}$						126	128				
	125	1								159			
	150	$1\frac{1}{4}$									195	207	

TABLE X—Part of Table of Ball Mill Sizes and Horsepower Requirements

Maker's mill size No.	Ball charge wt. (lb.)	Rpm	Motor hp	Capacity Tons 24 hours 65% Passing 200 Mesh	Capacity Tons 24 hours 85% Passing 200 mesh	Nett wt. only (lb.)
$9\frac{1}{2}$–11	90,000	19.1	500	820	576	156,500
$10\frac{1}{2}$–10	106,000	18.2	600	985	692	176,800
$10\frac{1}{2}$–12	124,000	18.2	700	1160	822	189,500
$10\frac{1}{2}$–14	142,000	18.2	800	1320	940	204,000
$10\frac{1}{2}$–16	160,000	18.2	900	1470	1040	220,000

$$E = E_p - E_f = K\left(\frac{1}{d} - \frac{1}{D}\right) \quad \ldots.(13)$$

This equation may also be expressed in terms of the reduction ratio by transforming as follows:

$$\frac{E}{1/\sqrt{d} - 1/\sqrt{D}} = K$$

Now also $$\frac{E_p}{1/\sqrt{d}} = K = \frac{E}{(1/\sqrt{d} - 1/\sqrt{D})}$$

or $$E_p = \frac{E/\sqrt{d}}{\frac{\sqrt{D}-\sqrt{d}}{\sqrt{D}\sqrt{d}}} = E\left(\frac{\sqrt{D}}{\sqrt{D}-\sqrt{d}}\right) \quad \ldots.(14a)$$

Dividing the latter fraction above and below by $\sqrt{d}$, then:

$$E_p = E\left(\frac{\sqrt{R}}{\sqrt{R}-1}\right) \quad \ldots.(14b)$$

where R = reduction ratio or D/d.

If now a work index E_i is postulated as the work required to break from an infinite size ($D = \infty$) to a specific product size of 100 microns, then substituting in Equation (13)

$E_1 = E_p - E_f = K\left(\frac{1}{\sqrt{100}} - \frac{1}{\infty}\right)$, i.e., $E_i = K/\sqrt{100}$, thus for an intermediate product size d

$$\frac{E_i}{1/\sqrt{100}} = \frac{E_p}{1/\sqrt{d}} = K$$

or substituting the value of E_p from (14a) and (14b)

$$\frac{E_i}{1/\sqrt{100}} = E\left(\frac{\sqrt{D}}{\sqrt{D}-\sqrt{d}}\right)\sqrt{d} = E\left(\frac{\sqrt{R}}{\sqrt{R}-1}\right)\sqrt{d}$$

whence $$E_i = E\left(\frac{\sqrt{D}}{\sqrt{D}-\sqrt{d}}\right)\cdot\sqrt{\frac{d}{100}}$$

$$= E\left(\frac{\sqrt{R}}{\sqrt{R}-1}\right)\sqrt{\frac{d}{100}} \quad \ldots.(15)$$

By means of this equation, BOND has determined the work indices of a large range of materials including glass, cement, clay, coal, flint, etc., in terms of kWh per short ton.[34] A number of work average indices are cited in Table VI. By rearranging Equation (15) and substituting the appropriate work index, the work involved in dry crushing and wet grinding operations may be evaluated thus:

$$E = E_i\left(\frac{\sqrt{D}-\sqrt{d}}{\sqrt{D}}\right)\sqrt{\frac{100}{d}} = E_i\left(\frac{\sqrt{R}-1}{\sqrt{R}}\right)\sqrt{\frac{100}{d}} \quad \ldots.(15b)$$

For dry grinding operations, however, the work is $\frac{4}{3}$ times that calculated by latter equation. BOND has developed a number of empirical formulæ by means of which several different types of laboratory tests may be used for the evaluation of the work index value of a given material.[34, 35]

In certain cases SCHUHMAN'S observations[33] (Equation 12) do not apply; neither are the slopes of the feed and product lines parallel. This applies in particular to scalped feeds or feeds which have had their fines removed. When the slopes of the feed and product lines show large divergencies, the energy involved in size reduction cannot be computed by means of Equation (16). In these cases BOND has suggested that an average reduction ratio, R_{av}, may be taken by averaging the reduction ratios at 90, 70, 50, 30 and 10% passing sizes. Thus:

$$E_i = E\left(\frac{\sqrt{R_{av}}}{\sqrt{R_{av}}-1}\right)\sqrt{\frac{d}{100}} \quad \ldots.(17)$$

BOND has shown by means of the following example how the knowledge of the work index of a given material may be used in the selection of suitable size reduction units.[34]

Example (5)

It is required to select a size reduction unit of 2000 short tons per day capacity to reduce a feed with 80% passing 3 in. to a product with 80% passing 100 mesh. The work index of the material is 13.0 kWh per short ton.

Solution

BOND shows how the selection might be made, assuming the material is first subjected to dry crushing in a hydrocone in open circuit, then to open-circuit wet rod milling and finally to closed-circuit wet ball milling. The crushing operation would provide for two seven-hour shifts per 24 hours (allowing the 8 and 16 hours for cleaning up) and the rod and ball milling operations would be operated continuously on a three eight-hour-shift basis per 24 hours. The specifications for these three stages of size reduction are set out in Table VII. The selection might then be made by referring to the performance characteristics of such units in tables given in manufacturers' bulletin, viz.:

Hydrocone Crusher

Table VIII shows crusher sizes and capacities. Since the selected crusher capacity must be in excess of 143 tons per hour, the next higher figure of 159 is chosen, i.e., a 548 crusher size with 1-in. eccentric throw. With 1-in. eccentric throw the motor hp. allowed on the crusher is a maximum of 125. Since only 90.3 hp is required by calculation, a 100-hp motor is selected.

Rod Mill

Table IX is part of a maker's selection table for rod mill sizes and capacities. The calculated hp = 316. Hence a 350-hp motor is required and this indicates that an 812 rod mill size (8 ft by 12 ft) is required.

Ball Mill

Table X shows some hp requirements for ball mills. This indicates that an 800-hp motor and a 10½, 14 ball mill (10½ ft by 14 in.) is required.

The following summarises the selection made.

Motor hp	100	350	800
Machine	Hydrocone crusher	Overflow rod mill	Overflow ball mill
Maker's size	548	812	10½-14

Criticism of Bond's Law

BOND has determined the work indices of over 1200 materials to establish his third theory of comminution. Previous work attempting to establish the validity of either RITTINGER'S or KICK'S law has lacked this comprehensiveness. Thus BOND'S theory as formulated in Equation (16), etc., is of divert economic value as a basis for the selection of size reduction equipment.

HOLMES[30] has directed attention to two fundamental objections to BOND'S Law in its present form—i.e., it ignores (a) the change of particle strength with particle size, i.e., it assumes that the work index calculated for a given material subjected to different degrees of size reduction will be the same for each reduction stage; and (b) the effect of the boundary conditions of the system which includes the size and shape of the feed particles and the manner in which the crushing force is applied.

To test the fundamental significance of BOND'S Law, HOLMES rigorously defined the work index for a given material and machine as *"the total work input in kWh/ton to reduce the material from theoretically infinite particle size to the product of normal distribution, 80% of which passes 100 microns, this reduction being performed under the same conditions and assuming the material characteristic to be the same as those prevailing during actual reduction over a finite size range in the*

machine considered" and carried out ball mill grindability tests on crystalline quartz, granite, gold ore and carboniferous limestone in order to test the variations of work index with fineness of product. The work index was determined on the basis of the following empirical equation:

$$E_{pb} = 20/G^{0.82} \qquad \ldots.(18)$$

where G is the ball mill grindability or net gram produced per revolution of the test mill, which passes a sieve opening of d mesh and by substituting the evaluated E_{pb} in the equation by BOND, viz.:

$$E_i = 0.80\ E_{pb}\left(\frac{d}{100}\right)^{\frac{1}{2}} \qquad \ldots.(19)$$

where d is defined by the 80% passing size for the material in question. HOLMES' results are summarised in Fig. 12, and show that work indices are not constant but increase with fineness as measured by decrease of size d corresponding to the mesh through which 80% of product passes. (The carboniferous limestone is exceptional in that the work index decreases with fineness.) More recent work by BOND shows that the work index is in fact a function of d (cf. Table XII).

The fact that work indices are variable in this way, despite constant boundary conditions, shows that BOND's Law in its present form merely empirically combines the laws of RITTINGER and KICK into a single law which has no fundamental significance. It is noteworthy, however, that BOND has put forward, but has not experimentally demonstrated, another theory,[33] i.e., that the useful work input is proportional to the length of the crack tips formed before fracture. For a break across a square cross-section of side D units the crack length is D; for a break across a cylindrical cross-section the crack length is $\sqrt{\frac{\pi D^2}{4}}$. BOND defined a dimension L as equal to the total crack length formed in the reduction of a short ton of material. The new surface formed by any reduction of a short ton equals $2L^2$. Effective cracks are crack tips which split the particle without the external application of additional energy other than that present in the stressed particle. Particle cracks which do not completely split the material would decrease the energy required for complete breakage in a subsequent reduction stage. Thus if an efficient grinding unit requires 300 joules per sq. m of new surface area produced, then the crack length produced per sq. m $= \sqrt{0.5}$ m, or approximately 77.5 cm, and the energy per cm of crack tip is $\frac{300}{77.5}$ or approximately 3.87 joules. The application of 3.6×10^7 joules per ton will result in the formation of a crack length 9.3×10^6 cm or 93 km. This aspect of BOND's third theory is difficult to evaluate without experimental demonstration, which at present is completely lacking.

The Fourth Theory of Comminution

Holmes' Law

The laws of RITTINGER, KICK and BOND may all be derived from the same mathematical basis. Thus if the energy involved in producing a change dD in the mean linear dimension D of a particulate material is dE, then:

assuming $$\frac{dE}{dD} = -CD^n$$

$$\int_0^E dE = -C\int_D^d D^n \,.\, dD$$

If $n = -1$, then

$$\int_0^E dE = -C\int_D^d \frac{dD}{D}$$

$$\text{or } E = C\log\frac{D}{d}$$

which is KICK's Law as expressed in Equation (11).

If $n = -2$, then

$$\int_0^E dE = -C\int_D^d \frac{dD}{D^2}$$

$$\text{or } E = C\left(\frac{1}{d} - \frac{1}{D}\right)$$

which is RITTINGER's Law as expressed in Equation (2).

If $n = \frac{-3}{2}$, then

$$E = 2C\left(\frac{1}{d^{\frac{1}{2}}} - \frac{1}{D^{\frac{1}{2}}}\right)$$

which is BOND's Law as expressed in Equation (13).

In general if $n = -y$

$$\text{then} \qquad \int_0^E dE = -C\int_D^d \frac{1}{D^y} \,.\, dD$$

$$\text{or} \qquad E = C\left(\frac{1}{d^{y-1}} - \frac{1}{D^{y-1}}\right) = C\,(d^{1-y} - D^{1-y})$$

if $y > 1$, then let $1 - y = -r$.

Hence $E = C(d^{-r} - D^{-r})$.

This suggests the possibility that the laws of RITTINGER, KICK and BOND are essentially different expressions of the same fundamental law in which r is a variable parameter. Thus the energy (E_f) involved in reducing to a feed size D is CD^{-r} and the energy (E_p) involved in reducing to a product size d is CD^{-r}.

HOLMES,[30] following the procedure of BOND in defining feed and product sizes, in fact, used an expression of the latter type, viz.:

$$S = \frac{1}{G} = Cd^{-b} \qquad \ldots.(20)$$

as a basis for the development of a new theory of comminution. In this expression, in which BOND had summarised the behaviour of a wide range of complex ores subjected to ball milling, S represents the resistance to grinding and is expressed as the reciprocal of the grindability G as defined by MAXTON, CADENA and BOND.[30] C and b are parameters having different numerical values for different materials.

HOLMES actually used KICK's Law which he derived in the form of Equation (9) as the starting point in the development of his theory. This equation is representative of the behaviour of perfectly annealed homogeneous isotropic materials, but for real materials permeated by cracks, flows and cleavage planes the stress (ψ, say) required to produce $2D^2$ units of new surface will be less than φ. The value of ψ will be determined according to HOLMES by:

(a) the particle size of the material, i.e., at coarse particle sizes a major proportion of the total reduction may be brought about by rupture of relatively weak VAN DE WAALS' bonds, but as particle sizes become smaller more and more strong covalent bonds must be broken; and

(b) the type of force employed by the size reduction machinery.

Thus Equation (9) may be rewritten as

$$\frac{\psi^2}{4M} \propto D^{-r}$$

and Equation (10) as

$$B = \frac{\psi^2}{4M} \,.\, D^{1-r} \qquad \ldots.(21)$$

where r is the "KICK's Law deviation exponent", a variable

TABLE XII—Showing Reasonable Constancy of Work Indices (Wi) with Variation of Product Fineness Defined by 80% passing Mesh Size d in microns.

Quartz		*Granite*		*Gold Ore*		*Carboniferous Limestone*	
$b = 0.77$ $q = 0.88$ $r = 0.68$		$b = 0.78$ $q = 0.94$ $r = 0.73$		$b = 0.62$ $q = 0.84$ $r = 0.52$		$b = 0.45$ $q = 0.74$ $r = 0.32$	
$d(\mu)$	W_i	$d(\mu)$	W_i	$d(\mu)$	W_i	$d(\mu)$	W_i
341	10.24	330	8.35	348	14.04	320	7.56
168	10.10	236	8.34	241	14.20	215	7.58
121	9.69	172	10.10	180	14.73	135	7.48
80	10.33	124	8.10	120	14.30	108	7.57
56.5	9.96	87.0	8.62	58	13.80	49.5	7.57
45.5	9.76						

parameter accounting for the change in particle strength with particle size, the type of material undergoing comminution, and the manner in which stress is applied.

Following the method adopted with Equation (10) for KICK'S Law, Equation (21) can be transformed into a general expression of the laws of RITTINGER, KICK and BOND. Thus the energy required to effect one fracture of area D^2 in a cube of side D is

$$E = 2\,BD^2 = kD^{1-r} \cdot D^2$$

and the energy required to produce three fractures of area D^2 (or to produce eight cubes of side $D/2$) is given by

$$E = kD^{1-r} \cdot 3D^2$$

and the energy required to reduce these eight cubes of sides $D/2$ to 64 cubes of side $D/4$ is given by

$$E = 8\,k\left(\frac{D}{2}\right)^{1-r} \cdot 3\left(\frac{D}{2}\right)^2$$

Thus by considering successive reductions in particle size, Table XI was constructed.

Now considering the energy to reduce a cube of side D to cubes of side d where $d = D/2^x$:

Reduction ratio $= R = D/d = 2^x$

$$\therefore\ x \log 2 = \log R \text{ or } x = \frac{\log R}{\log 2}$$

and from Table 5 $x = \dfrac{\log R}{\log 2}$

$$E = 3\,D^2 \sum_{x=1}^{x=\frac{\log R}{\log 2}} \frac{2^{x-1}\,kD^{1-r}}{2^{(x-1)(1-r)}}$$

$$= 3\,k\,D^{2-r} \sum_{x=1}^{x=\frac{\log R}{\log 2}} 2^{(x-1)^2}$$

Now $$\sum_{x=1}^{x=\frac{\log R}{\log 2}} 2^{(x-1)^r} = \frac{1-2^{r\left[\frac{\log R}{\log 2}\right]}}{1-2^r} = \frac{R^r-1}{2^r-1}$$

$$\therefore E = \frac{3\,k\,D^{2-r}\,(R^r-1)}{2^r-1}$$

This is a general expression for the energy required to reduce a cube of side D to cubes of side d and corresponds to an expression of RITTINGER'S, KICK'S or BOND'S Law if $r = 1$, D or $\frac{1}{2}$ respectively. For the reduction of unit weight of material of size D to size d, the energy requirements will be $1/\delta D^3$ times greater; thus

$$E = \frac{3k\,D^{-r}\,(R^r-1)}{\delta\,(2^r-1)} \qquad \ldots.(22)$$

where δ = density of material.

From Equation (20) HOLMES derived an expression analogous to the basic expression of BOND'S Law (Equation (13)), viz.:

$$E = K\left(\frac{1}{d^r} - \frac{1}{D^r}\right) = K\left(\frac{R^r-1}{R^r}\right) \cdot \frac{1}{d^r} \qquad \ldots.(13a)$$

by making the assumptions that:

(1) the geometrical configurations of the particles does not alter the form of Equation (19);
(2) the size distribution of the particles can be expressed by Equation (12);
(3) the product is substantially independent of the boundary conditions, as in ball milling, where reduction involves the transformation of the transient mode of a relatively coarse material into the persistent mode of a finer material (cf. Fig. 9);
(4) the efficiency defined as

$$\eta = \frac{\text{work input required to initiate particle fracture}}{\text{total work input to mill}}$$

is constant for any one material and machine. Any possible variation of η with product size is assumed to be incorporated in r.

HOLMES transformed Equation (13a) to an expression analogous to Equation (16), viz.:

$$E = E_i\left[1-\left(\frac{1}{R}\right)^r\right]\left(\frac{100}{d}\right)^r \qquad \ldots.(16a)$$

The work index was rigorously defined, as already described following assumption (3) above.

In order to interpret his results for the ball mill grinding of quartz, granite, gold, ore and carboniferous limestone, HOLMES modified Equations (18) and (19) as follows:

$$E_{pb} = \frac{A}{G^q} \qquad \ldots.(18a)$$

$$E_i = 0.80\,E_{pb}\left(\frac{d}{100}\right)^r \qquad \ldots.(19a)$$

where A and q are parameters which vary from material to material.

Thus $$E_i = \frac{0.80A}{G^q}\left(\frac{d}{100}\right)^r \qquad \ldots.(23)$$

Now the relationship of G to d, as expressed in Equation (20) and plotted on a log-log scale, is linear. Transformed, this equation is

$$G = d^b/C \qquad \ldots.(20)$$

Thus G can be eliminated from Equations (20) and (23), giving

$$E_i = \frac{0.80AC^q}{100^r} \cdot \frac{d^r}{d^{bq}} \qquad \ldots.(24)$$

For a constant work index $r = q.b$ (otherwise $E_i = f(d)$) and hence

$$E_i = 0.80A.C^q/100^r \qquad \ldots.(25)$$

C and b can be determined from the plot of G against d on a log-log scale. A and q are obtained by a method of successive aproximations from Equation (24) (see Ref. 37). Proceeding in this way, HOLMES obtained the results in Table XII for the materials tested. Thus the work index as evaluated on the basis of HOLMES' theory shows little variation with product fineness, and within the limits of experimental error is reasonably constant.

The relationships between the theories of RITTINGER, KICK, BOND and HOLMES are illustrated in Fig. 13 plotted for carboniferous limestone according to the equations:

RITTINGER

$$E = K_1\left(1 - \frac{1}{R}\right)\frac{1}{d}$$

KICK

$$E = K_2\frac{\log R}{\log 2}$$

BOND

$$E = K_3\left[1 - \left(\frac{1}{R}\right)^{\frac{1}{2}}\right]\frac{1}{d^{\frac{1}{2}}}$$

HOLMES

$$E = K\left[1 - \left(\frac{1}{R}\right)^{r}\right]\frac{1}{d^r}$$

The value of d is expressed in the same way in each of these equations, so that K_1, K_2 and K_3 vary with d, but $K = 100^r . W_i$ is a constant for one material and one machine. It is evident from Fig. 13 that the results approximate more closely to the "true" or HOLMES' Law result in the order BOND, KICK, RITTINGER.

Summary and Conclusion

This article began by considering the problems of selecting equipment for size reduction and discussed the methods by which mills could be operated with the minimum expenditure of power. It was shown, *inter alia*, that the selection of machine and motor sizes and efficiency comparisons depend ultimately upon the ability to predict power requirements. The inadequacy of KICK's and RITTINGER'S Laws for this purpose was discussed, as well as their mutual incompatibility and their reconciliation in a single law as BOND'S third theory of comminution. Finally, all three laws were shown to be but special cases of a more fundamental law in which the variation from ideal KICK'S Law behaviour of perfectly annealed homogeneous isotropic materials is expressed as a parameter r which varies from material to material and is termed the KICK'S Law deviation exponent by J. H. HOLMES.

The value of r was determined by HOLMES for a number of minerals by carrying out ball milling tests and by adapting certain equations of BOND to evaluate the results obtained. Within the restricted range of size reduction operations and for a given material and particular machine, HOLMES found a constant value of r. It is stressed, however, in HOLMES' paper that for coarser crushing systems, where transient rather than persistent mode material is being produced, variation in the fundamental form of the HOLMES' equation or in the value of r may possibly take place for a given material. The type of size-reducing force and its rate of application may also be critical factors causing r to differ for any one material.

One of the difficulties which will be encountered in attempting to solve this problem is the absence of a single equation applicable to all size distributions. It would appear more advantageous, temporarily at least, to circumvent the problem by the use of mean particle size as determined by specific surface measurements, or alternatively, by an adaptation of the graphical procedure used in the evaluation of specific surface from size distribution data. Thus Equation (13a) might be written in the form

$$E = K\ S'_w{}^r - S_w{}^r \qquad \text{[cf. Equation (11a)]}$$

If the strength of a given material decreases with increase of particle size, then it is obvious that relative to size reduction processes we are dealing with a different material at the 100-micron level than at the 1000-micron level of mean particle size, and hence variation of r may be anticipated over the range of mean particle sizes from 100 to 1000 microns. If this variation is due to internal flaws and fissures, the variation of the specific gravity of the material with particle size (determined possibly by a "sink or swim" or flotation method using liquids of different specific gravity) should provide a measure of the relative strengths of the particles. POWERS[38] has found such a variation in the specific gravity of sucrose crystals.

The purpose of all size-reduction studies will in the future be either directly or indirectly associated with the problem of assigning values to r for individual materials and machines and in determining the factors which cause variation from material to material.

It is possible that some factor such as the Moh hardness number may be involved in such a correlation. Thus BOND and WANG[39] obtained a graph which shows the variation of power input (E) with $\frac{R}{d}$ for materials of different degrees of hardness (not, however, measured by Moh hardness) and for different machines (Fig. 14).

Until such developments take place, BOND'S Law will lead on account of the wide range of test data covered.

REFERENCES

[1] Davis, A. C. *Portland Cement*, Concrete Publications Ltd.
[2] Meade, R. K. *Portland Cement*, Chemical Publishing Co.
[3] Newman, A. C. C. Inst. Chem. Eng. Symposium on Particle Size Analysis, 1947, **69**.
[4] Smith, J. C. *Chem. Eng.* 1952, **59**, No. 8, 151-66.
[5] Dean and Gross. U.S. Bur. Mines Rept. Investigations 3118 (1932); 3201 (1933) Gross; ibid. 3223 (1934), 3268 (1935).
[6] Mohs, F. "Grundriss der Mineralogie", 1824. Translation by W. Hardinger, *Treatise on Mineralogy*, Constable, Edinburgh, 1825.
[7] Perry, J. H. "Chemical Engineers Handbook", McGraw-Hill, London, third edition, 1950, p. 1103-60.
[8] Tabor, D. *Proc. Phys. Soc.*, B. 1954, **67**, 249-57.
[9] Piret, E. L. *Chem. Eng. Prog.*, 1953, **49**, No. 2, 56-63.
[10] Foote, J. H. *Chem. Eng. Prog.*, 1953, **49**, No. 2, 68-72.
[11] Erickson, H. W. *Chem. Eng. Prog.*, 1953, **49**, No. 2, 63-68.
[12] Work, L. T. *Chem. and Met. Eng.*, 1933, **40**, 306.
[13] Farrent, J. C. and North, R. "Chem. Eng. Practice", Butterworths Scientific Publications, London first edition, 1957, **3**, 48-96.
[14] Dallvale, J. M. "Micromeritics", Pitman, London, 1948, Chap. 22.
[15] Kelleher, J. "Estimation and Control of Efficiency of Chocolate Refining Operations", British Food Manufacturing Industries R.A., Scientific and Technical Surveys, No. 29, July, 1956.
[16] Schweyer, H. E. *Indust. Eng. Chem.*, 1942, **34**, 1060-65.
[17] Kelleher, J. "Studies on the Smoothness of Chocolate." B.F.M.I.R.A. Research Reports, No. 70, May 1956. (Confidential for Members only.)
[18] Heywood, H. *J. Imp. College, Chem. Eng. Soc.*, 1950-52, **6**, 26.
[19] Nijman, Ir. J. *Brit. Chem. Eng.*, 1958, **3**, 76-80.
[20] Heywood, H. "Chem. Eng. Practice", Butterworths Scientific Publications, London, first edition, 1957, **3**, 1-23.
[21] Rittinger, P. R. von. "Lehrbuch der Aufbereitungskunde", Berlin, 1867, p. 19.
[22] Gates, A. O. Eng. Min. J. 1913, **95**, 1,039.
[23] Bond, F. C. *Trans. Amer. Inst. Min. (Metall.) Eng.* Tech. Publ. No. 33,088 (*Mining Eng.*, 1952, 484-94).
[24] Lowrie-Fairs, G. *Trans. Instn. Min. Metall.*, London, 1953-4, **63**, No. 5, 211-40.
[25] Martin, G. *J. Soc. Chem. Ind.*, 1926, **45**, 160-3T.
[26] Heywood, H. Conference on Pulverized Fuel. Institute of Fuel, 1947, 594-611.
[27] Gaudin, A. M. "Principles of Mineral Dressing", McGraw-Hill, New York, 1939, Chap. 6.
[28] Fahrenwald, A. W., Hammer, O. W., Lee, H. E. and Stalley, W. W. *Trans. Amer. Inst. Min. (Metall.) Eng.* Tech. Publ. No. 416, 1931.
[29] Kick, F. "Das Gesetz der Proportionalen Wiederstande und seine Anwendung", Leipzig, 1885.
[30] Holmes J. A. *Trans. Inst. Chem. Eng.*, London, 1957, **35**, 125-41.
[31] Stadler, H. *Trans. Inst. Min. Metall.*, London, 1910/1911, **19**, 478.
[32] Andreason, A. H. M. *Trans. Inst. Chem. Eng.*, London, 1957, **35**, 104-10.
[33] Schuhmann. R. *Trans. Amer. Inst. Min. (Metall.) Eng.* Tech. Publ. No. 1, 189, 1940 (*Chem. Abstr.*, 1940, **34**, 5386).
[34] Anon. "How to Determine Crusher and Grinding Mill Sizes Accurately". Allis-Chalmers Mfg. Co., Milwaukee, 1953.
[35] Bond, F. C. "Crushing and Grinding Calculations", Allis-Chalmers Mfg. Co., Milwaukee, 1955.
[36] Maxton, W. H., Cadena and Bond, F. C. *Trans. Amer. Inst. Min. (Metall.) Engrs.*, 1934, **112**, 130.
[37] Holmes, J. A. Atomic Energy Research Establishment Report, CE/R 1698.
[38] Powers, H. E. C. "La Cristallisation du Sucre", Commission Internationale Technique de Sucrerie de Betterave Compte-Rendu de la VII^e Assemblee Bruxelles, 1953.
[39] Bond and Wang. *Trans. Amer. Inst. Min. (Metall) Eng.*, 1950, **187**, 871.

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DESIGN OF PROCESS EQUIPMENT TO ECONOMIC OPTIMUM

An analysis of the relative merits of four methods of performing optimum design calculations

by J. J. TABOREK*

Introduction

WHILE a careful economic analysis of an overall venture is a standard procedure, the optimisation calculations at the level of the actual designs, where the capital expenditures are ultimately fixed, has often been neglected.

The reasons for this situation are not difficult to spot:

(1) Only a few straightforward cases are applicable for solution by relatively simple analytical methods. The majority will contain discontinuous functions or other complications which will require stepwise solutions, often with respect to several optimisation parameters. Such calculations are, however, extremely time-consuming and highly unpopular with the engineers.

(2) Many a conscientious engineer has experienced bitter disappointment to find, after tedious calculations, that the cost curve around the optimum point was extremely flat. The incremental saving, even if actually realised, was hardly worth the effort expended.

(3) The uncertainty of the mathematical relationships underlying the design calculations favoured the more or less legitimate use of safety factors, rules of thumb, or decisions based on "established practices".

(4) Management sometimes looked rather favourably on intentional over-designs with the convenience of the "built-in" potential for capacity increase.

Several points of this hitherto sound philosophy should be subjected to basic revisions as a result of the developments of the past decade.

Improved understanding of many engineering processes allows equipment performance prediction with unprecedented accuracy. This has been helped particularly by the availability of electronic computers which do not set the narrow limits to the intricacy of the mathematical models used. Intense competition in many fields lets even marginal savings in the operational cost appear more lucrative than they used to be.

The objective of this report is to survey critically some of the methods and practices for equipment design optimisation, especially with respect to the use of digital computers.

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General Logic of Equipment Optimisation

Most problems of engineering equipment design have several if not, at least theoretically, an infinite number of solutions. The objective of optimisation is then to select out of the multiplicity of potential solutions the one which is "best" with respect to some desired property. While this variable can be any particular design parameter such as overall size, ground space, weight, hold-up volume, etc., the most frequently encountered problem will be that of cost, which will be also the basis for the following deductions.

Economics of Process Operation. The general definition of the financial aspects of a process is that the profit P (\$) is the difference between the value of the product V (\$) and the cost of performing the operation C (\$).

$$P = V - C \qquad \ldots (1)$$

The cost of operation C can be broken down further to any desired detail, but two substantial groups can be distinguished:

The fixed cost I (\$), which includes the cost of initial installation and all factors depending on its value.

The operating cost E (\$), which includes all the cost components connected with running the facility, such as energy supply, regular and major maintenance, etc.

Consequently:

$$C = I + E \qquad \ldots (2)$$

The optimum design is that which will produce maximum profit. Not always will an optimum exist. The condition is that (a) one or more operational parameters can be varied within sufficiently wide range to effect substantial changes in the equipment design and its cost; (b) at least two of the profit components V, I and E will be affected by such variations in mutually opposite directions (i.e., one will increase while the other decreases) or, if changing in the same direction, their respective rate of change will be sufficiently different to produce an inflection point.

Two typical examples can be given:

Example 1. The value of the product V and operation cost C are variable with an operational parameter p. This situation would apply to the design of a reactor where the operating pressure is the variable. The product value will

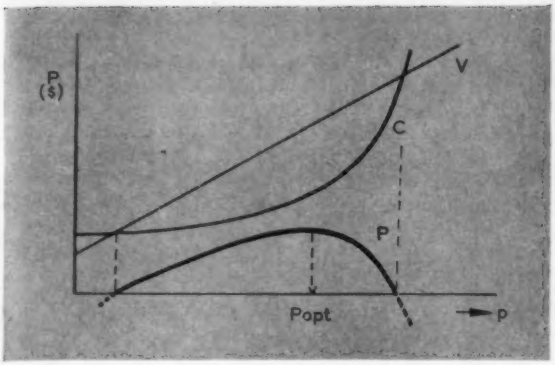

Fig. 1. The optimum operating pressure for the design of a reactor in which pressure is the variable.

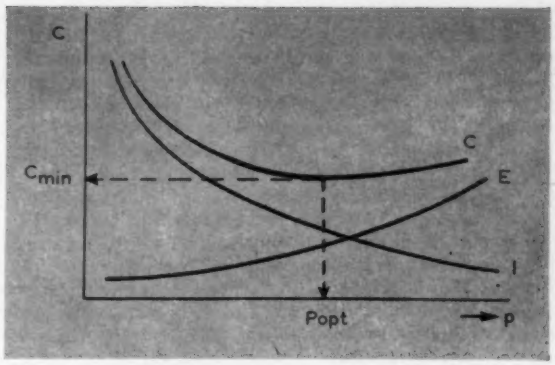

Fig. 2. The conditions for the design of an optimum heat exchanger.

increase with pressure due to higher conversion, but also the cost of the apparatus and its operating cost will increase with pressure. The rates of increase are, however, different and an optimum will exist at p_{opt} (Fig. 1).

Example 2. In most cases of equipment design the result of the operation will be an intermediate product to which no value can be easily attached. In such cases V is constant, and an optimum design will be possible only if the component factors of the operational expenses I and E form a minimum total expense C, which will be then identical with maximum profit. A practical example of this case is the design of an optimum heat exchanger for specified duty and fixed temperatures. The heat exchanger is a part of a complex process and no value can be reasonably attributed to its function. The independent variable of optimisation is in this case the flow velocity of the fluids. The higher the flow velocity, the smaller will be the required area and the fixed cost, but the higher will be the cost of producing the flow velocity required. The cost components I and E change magnitude in opposite direction, thus fixing an optimum at p_{opt} (Fig. 2).

The Extent of Process Circuit. The extent of the process circuit which should be included in the optimisation calculations commands particular interest. Whenever there is an operational parameter common to several units, vigorous optimisation will be possible only if carried out on the entire circuit involved. The extent of such calculations will frequently be prohibitive, and simplified mathematical models for the individual units will have to be introduced. However, establishing the optimum with respect to the overall process will bear much greater validity than the opposite process of optimising the smaller circuits independently, which will not necessarily lead to an overall optimum.

Optimisation Methods

Having defined the basic economic equations for the circuit subject to optimisation, we have several methods of establishing the optimum values of the design parameters.

(1) Analytical Solution

Classical Method. This method is based on the classical mathematical theorem that equating the first differential of a function to zero and solving for the variable will deliver the position of the peak.

Optimisation by this classical method is possible in all such cases where we deal with continuous parameters and equations, which in their differentiated form allow explicit solution for the optimisation parameter. Unfortunately, these conditions apply only in exceptional cases for engineering equipment designs. Nevertheless, several analytical optimisation solutions for equipment design have been worked out, especially in the heat-transfer field.[1, 2, 3, 4, 5] This was possible only after the introduction of more or less bold simplifications (e.g., cost of heat exchangers assumed proportional to area).

For these reasons, optimisation of equipment design by the classical analytical method has been predominantly used only to demonstrate effects of optimisation parameters on typical examples and to establish generalised design rules. In many cases this leads to very practical and useful design methods, but the user should be aware of the conditions restricting the validity of such developments.

Problems Containing Restrictions. Most of our engineering equipment is subject to a number of dimensional or operational restrictions derived from commercial availability, standard size series, manufacturing practices or process limitations. Consequently, we will find very often that the analytically determined optimum could not be translated into actual design without further adjustments. The question, however, which of several alternate possibilities would come closest to the optimum, can only seldom be answered by the classical analytical method and in any case will require additional calculations.

To deal with cases where restrictions are imposed, we have available a modification of the classical analytical method, in which use is made of Lagrange's undetermined multipliers. Any arbitrary number of restrictions can be imposed, but the mathematical complications rise rapidly beyond practical limits.

(2) Method of Steepest Ascent

This method, widely used in experimentation, can also be applied to design optimisation. Let us imagine the relation between the optimisation parameters as a multidimensional surface with the profit as a dependent variable. The method will seek out the peak of the surface closest to the starting conditions by progressing incrementally in the direction of the maximum gradient. The difficulty in the mathematical solution is considerable and this method is presently not very popular.

(3) The "Case Study Method"

The mechanics of solution by what we may term as "case study method" are the simplest possible: a set of complete

design solutions for the equipment units involved are obtained at selected values of the optimisation parameter, judiciously scattered around the expected optimum point. If the first set of assumed values did not include the optimum, it has probably indicated the trend, and subsequent selection will be progressively more accurate, until the optimum is reached or its position can be constructed as inflection point of a curve.

The final presentation of the results is by a tabulation or, preferably, a graphical plot of cost vs. the operational parameter. To establish this relation, the solution of each case, i.e., the design to each assumed value of the optimisation parameter, must be subjected to an individual economic analysis. This will consist, essentially, of establishing all the factors required for the solution of the operating cost equation: the initial equipment cost and the operating and maintenance cost. While the procurement of such values for each case individually will have the disadvantage of being inherently tedious, the accuracy of the calculation can be carried to any desired and individually controllable level. This is in particular contrast to the analytical method, which will permit only generalised cost definitions.

The result of these calculations will be a curve in case of completely continuous relations between the variables, or a step-function, in case of dimensional or other restrictions. The evaluation of the results will include not only the primary objective of establishing the optimum design, but the cost curve will deliver, in most effective form, information about the relations between the overall cost and the optimisation parameter throughout a wide range of potential solutions.

Critique of Optimisation Methods

Let us now compare some of the outstanding properties of the optimisation methods.

The analytical method will deliver the mathematically most elegant solution, but will also have severe limitations:

(1) It requires that the functions involved be differentiable. This presents a problem when we deal with discontinuous or for other reasons not differentiable functions (e.g., LMTD correction factor).

(2) In many cases it will be necessary to introduce only simplified relations between the equipment cost and the operational parameters in order to keep the complications of solution within limits.

(3) The result will be a single point solution which will not give any indication about the shape of the optimum surface, i.e., direction in which eventual deviation should be made.

(4) This method cannot deal with cases involving unpredictable deviations from original assumptions such as changes between laminar and turbulent flow.

(5) It is the only method which can handle more than two simultaneous variables. The difficulties in the mathematical solution will, however, increase rapidly with the number of variables, particularly if the method of undetermined multipliers is used or when we deal with groups of equipment. In such cases a special solution and programme will have to be developed for each particular problem.

The case study method is exceptionally well suited for computer use.

Let us assume that a general programme for designing certain process equipment is available. Then this same programme can be used for optimisation calculations simply by solving the design for several values of the optimisation parameter. Any of the operational parameters and their combination can be subjected to optimisation with the same general programme and without any additional programming as long as such parameters appear as input variables in the programme.

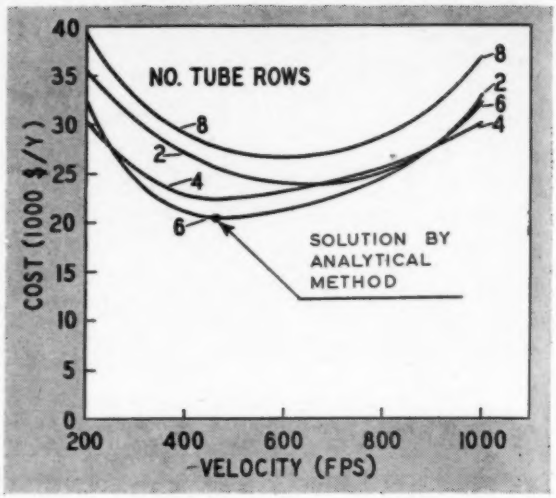

Fig. 3. Optimum air cooler design.

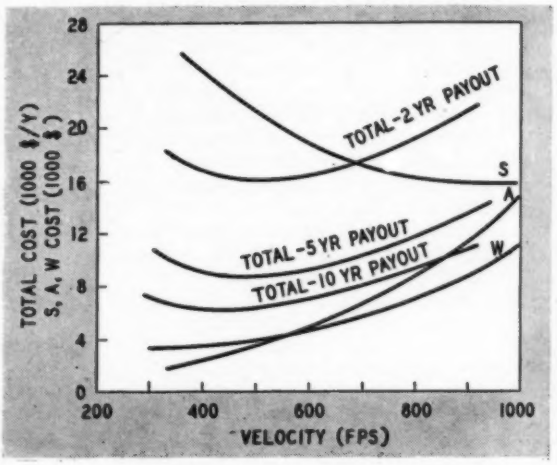

Fig. 4. Cost analysis of air cooler (four-tube row construction).

The complete economic calculations, including an unrestricted unit cost estimation, can also be included as a part of the computer programme. Moreover, as the design solution to each value of the operational parameter was subjected to restrictions inherent to any particular situation, these solutions will be real and directly eligible for final selection. An example is presented in Appendix 1.

A particular advantage of the case study method is that even groups of various equipment units appearing in process circuits can be optimised by this method without developing a special programme. So compressor and inter-cooler optimisation can be accomplished by the use of separate compressor and heat exchanger programmes.

An example of optimising the combination of an air cooler and water cooler shell and tube heat exchanger by using two separate programmes is given in Appendix 2.

Presently, for the evaluation of multiple units systems with a common parameter, separate programmes followed by a graphical interpretation are being used. This is, however, not a functional, but rather a technical limitation of the method.

As computers with larger memory storage capacities will be available, several equipment design programmes can

be working simultaneously, hooked up with only a simple common logic of optimisation.

A serious limitation of this method is that it almost unconditionally requires a graphical form of result representation which is limited by the restrictions inherent to our three-dimensional space. Fortunately, many engineering design problems will deal with not more than two simultaneous variables, or most of those that do can be reduced to such cases by assuming selected values for the higher degree variables.

Appendix 1

Optimum Design of Air Coolers

In designing an air cooler for a given temperature and duty, there are a large number of possible solutions, with the air velocity and the depth of the coils (number of rows) being the variables. The higher the air velocity, the higher will be the air film coefficient and the smaller unit will be required, but, also, the higher will be the pressure drop and the work required of the fan. Higher numbers of rows will permit the concentration of large heat transfer areas in small units, requiring less expense for structures. The film coefficient will (at least for induced draught) increase with number of rows as a result of better turbulency. Consequently, it is favourable to use a high air velocity and a high number of tube rows, until restricted by (a) too high pressure drop, for which no suitable fan is commercially available; (b) the saving on exchanger cost is offset by high initial and operating cost for the fans.

The optimisation of air cooler design by an analytical method has been shown by Kern.[5]

Expressing the total yearly cost for y (years) payout time as a function of the heat transfer area A, the pressure drop $\triangle P$ and the air flow W in terms of the operational variables V and N, we get, after differentiation, two simultaneous equations from which the optimum value of the parameters can be determined by a trial-and-error convergency. If the optimised design does not fit to commercially available units, adjustments will have to be made, but the analytical method will not indicate in which direction the change will be preferable or how much such deviation will cost.

The basis for solving this problem by the case study method is a design solution of the air cooler for a series of given air velocities and number of tube rows. The engineer setting up the data will specify the lower and upper limits of V and N and the computer will automatically supply solutions of all possible combinations between these variables. The cost of each unit, including air fans, is estimated in the computer by solving a set of predetermined cost equations which can be made much more accurate than the generalised correlations used, by necessity, for the analytical method.

Solution of an example as supplied by the computer is shown in Fig. 3, plotted as yearly cost vs. air velocity with number of rows in parameter. The curves do not show any consistent pattern due to the fact that non-practical solutions have been eliminated by the computer and adjusted to actually available units. The optimum falls into the 450-600 ft/min range, which coincides with the general predictions of the analytical method. One case (four-row design) is broken down in the cost components in Fig. 4. The effect of pay-out time is also demonstrated, showing a shift to lower velocities with increasing pay-out time, i.e., toward designs with larger initial cost and smaller operating cost.

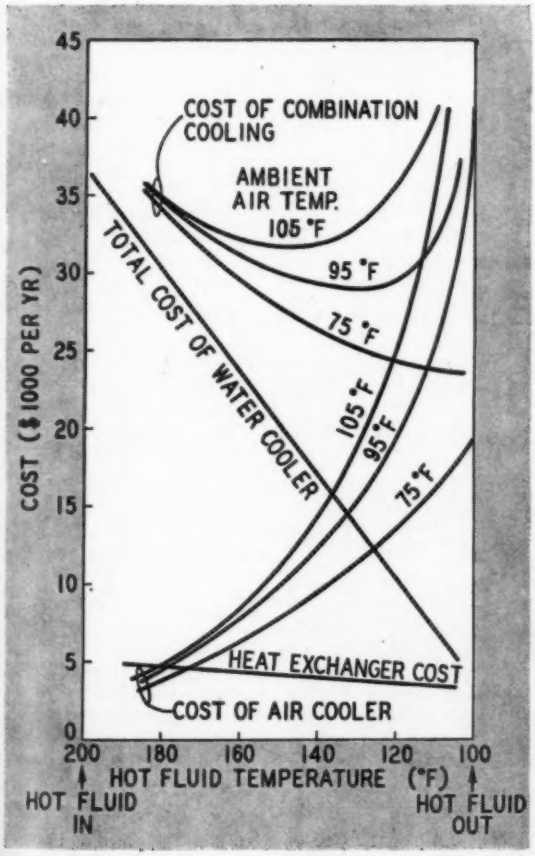

Fig. 5. Economic analysis of air cooling.

Appendix 2

Optimised Selection between Air vs. Water Coolers

The example problem is to cool a hot oil stream from 200°F to 100°F. This can be done by air cooling, water cooling or a combination of both. The economic decision in favour of any one of the possibilities will depend upon a number of process conditions (the temperature range of the hot fluid, inlet temperature and permissible rise of the cooling water, ambient temperature of the air) and some overall economic factors, in particular the cost of supplying the cooling water.

For our example the cooling tower cost, including supporting facilities of \$2200/MBtu/h, was assumed and 5% make-up water was required at a cost of \$0.12/1000 gal. Pay-out time of two years with 10% interest rate on investment was set.

Complete design calculation for air coolers for three ambient air temperatures of 75°F, 95°F and 105°F were obtained from a computer programme for various heat duties keeping the hot inlet temperature constant and decreasing the hot outlet temperature up to the full cooling range. The economic analysis of each design was automatically supplied by the computer programme and results plotted against the hot outlet temperature in Fig. 5. The intercepts of these curves with the given hot outlet temperature shows the cost of the cooling by air alone. Notice that the 105°F ambient air temperature will intercept at an unrealistically high cost, thus making the use of a trim water cooler mandatory.

The cost of the water cooler was also determined from a computer programme, but this time the hot outlet temperature (100°F) was kept constant while the heat duty was varied by changing the hot inlet temperature for the full range. The cost of the heat exchanger alone was raised only slightly despite the large differences in the total heat duty, as these were offset by the increasing temperature dif-

ferences. However, the amount of water with the corresponding charge for the cooling tower facilities was proportional to the heat amount transferred. The intercept of the curve with the given hot inlet temperature determines the cost if water cooling is used.

For the 75°F air ambient temperature, total cooling by air is preferable by a wide margin. For 95°F the total air cooling would require slightly higher cost than total water cooling, but the combination of air and water cooling with about 130°F trim temperature is the economic optimum. For 105°F ambient temperature total air cooling is impossible and the air-water combination with about 145°F trim temperature shows a distinct economic optimum.

Each of the air cooler designs taken as a basis for this evaluation was by itself an optimum design with respect to air velocity and tube row depth as supplied automatically by the computer programme.

REFERENCES

[1] Schweyer, H. E. "Process Engineering Economics", McGraw-Hill, New York, 1955.
[2] Happel, J. "Chemical Process Economics", John Wiley & Sons, New York, 1958.
[3] Cichelli, M. T., and Brinn, M. S. "How to Design the Optimum Heat Exchanger", *Chem. Eng.*, Vol. 63, No. 5, May 1956.
[4] Kern, D. Q. "Optimum Air-fin Cooler Design". Paper presented at the Second National Heat Transfer Conference, A.I.Ch.E.-A.S.M.E., Chicago, Ill., 1958.
[5] Kern, D. Q. "Optimum Trim Cooler Temperature". Paper presented at the Symposium on Air Cooled Heat Exchange at the A.I.Ch.E. Meeting in Cincinnati, Ohio, 1958.

Calculating Thickener Areas with Unknown Solid Content Suspensions

by A. BANIEL, L. BLUM and A. SEROUSSI*

IT has been found possible to compute thickener areas from standard settling tests without reference to solids content of feed pulp or of underflow. This result, of practical importance in the case of pulps containing strongly hydrated solids, is achieved through a simple algebraic transformation of currently used formulæ.

Solid to liquid ratios intervene in all currently used formulæ for deriving thickener areas from batch settling tests. This is the case in particular for the procedures proposed by COE and CLEVENGER[1] and for the procedure proposed by TALMADGE and FITCH which is based on KYNCH's analysis of settling.[2]

In laboratory settling tests we only observe the evolution in time of the relationship between the height of the clear column to the height of the thickened column. Solid contents do not enter into these observations at all. It should be possible, therefore, to reduce formulæ applying the results of settling tests to forms wherein only observed magnitudes intervene, i.e., column heights (or volumes if the cross-section of the vessel involved is uniform).

Let us take the Kynch formula as example. It may be written as[3]

$$A = \frac{t_u}{C_o H_o} \text{ m}^2 \text{ per ton solids per day}$$

where t_u = time in days;
H_o = initial height in meters; and
C_o = initial solid to liquid ratio (t/m³).

Let A_v be the area per 1 m³ of feed. The daily feed volume V may be known independently of the true solids content. The required minimum thickener area will be VA_v. If T is the total quantity of solids fed per day (and which may not be known) the same minimum area is also AT.

By replacing C_o by T/V and equating $AT = VA_v$, we find:

$$A_v = \frac{t_u}{H_o} \text{ or } VA_v = \frac{Vt_u}{H_o}$$

The Coe and Clevenger formula may be similarly transformed. The same obtains for the usual correction for a compression zone of 3 ft depth.

Expressed in terms of volumes, the formulæ reflect directly empirical observation and their use is less subject to errors through the introduction of solid to liquid ratio. This entity, appearing in the denominator, introduces uncertainties in the current practice of computing thickener areas when the solids content is small. In many cases, such as clays, various effluent sludges, hydrated alumina, it is difficult to determine solids content with precision. The authors were led to evolve the proposed transformation through their studies on the settling of liquors obtained by digesting phosphate rock with hydrochloric acid.[3]

It is suggested that formulæ based on volumes only should be considered as fundamental in thickener area computation. The introduction of throughputs of solids is optional and should be treated separately.

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ACKNOWLEDGMENT

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REFERENCES

[1] COE, H. S., and CLEVENGER, G. H. "Laboratory Method for Determining the Capacities of Slime-settling Tanks", *Bull. Am. Inst. Mining Eng.*, 1916, 597-625.
[2] TALMADGE, W. P., and FITCH, E. B. "Determining Thickener Unit Areas", *Ind. Eng. Chem.*, 1955, 47, 38-41.
[3] BANIEL, A., BLUMBERG, R., and ALON, A. "Phosphoric Acid by Liquid-liquid Extraction", *British Chemical Engineering*, April 1959.

A Dorr-Oliver thickener at the Steetley Co.'s Hartlepool sea water magnesia plant.

66.047.32 : 66.074.66

THE TREATMENT OF NITRIC ACID PLANT TAIL GAS

An outline of the most recent catalytic combustion technique for eliminating nitrogen dioxide

by W. FLETCHER, F.R.I.C.*

AN exhaust plume varying from yellow to reddish brown in colour commonly shows the presence of a nitric acid plant or nitration process. The colour arises from the presence of NO_2 left unabsorbed and unreacted in the absorption section of the nitric acid plant. The tail gas from the absorption tower usually contains 0.3-0.5% NO_2 and 2-4% of excess oxygen, the balance being nitrogen.

The presence of the NO_2 in the tail gas creates a corrosion and atmospheric pollution problem locally and is claimed to promote smog formation over wider areas than the immediate neighbourhood of the plant. With statutory requirements and clean air legislation to be complied with, work has been carried out (mainly in the U.S.A.) on the reduction by catalytic means of the offensive NO_2 content of tail gas to inert nitrogen.

Processes

In some plants the tail gases are cleaned by scrubbing with caustic soda solution in a packed column, producing a mixture of sodium nitrate and sodium nitrite. Since this mixture requires separation and raises problems of disposal, the process has a limited application.

An alternate process is shown in Fig. 1, which is a flow diagram of a typical arrangement for carrying out the catalytic reduction. In this process the tail gas leaving the absorber has a composition: nitrogen oxides—as NO^2—0.3-0.5% v/v, oxygen, 2-4%, nitrogen the balance, is at a temperature about 30-35°C and at a pressure of up to 90 psig according to the process used for nitric acid manufacture.

As the temperature required for initiation of the catalytic reduction is between 149°C for hydrogen fuel and 400°C for methane, it is necessary to preheat the tail gas before adding the fuel. This is done by heat exchange with the hot process gases in the nitric acid plant.

The reduction is carried out by mixing the tail gas with a quantity of fuel gas slightly greater than stoichimetric requirements and burning the mixture on a catalyst bed when the following exothermic changes occur:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$
$$2NO_2 + CH_4 = CO_2 + 2H_2O + N_2$$

The significantly large quantities of heat produced are recovered, either by a waste heat boiler in the form of steam or by a gas turbine or a combination of the two.

Fuels

A wide range of fuel gases may be used, including hydrogen, natural gas, petroleum gases, coke oven gas and carbon monoxide. Of these, hydrogen is preferred when economically available, as it operates at a lower initial temperature than methane and other hydrocarbons, and gives a better overall performance in NO_2 reduction.

The quantity of fuel used is slightly in excess of that theoretically required to reduce the O_2 and NO_2 present. The amount of fuel is also limited by the upper temperature limit the catalyst used will tolerate. Where a single-stage operation would exceed this limit, two stages are used with intermediate cooling, and the fuel is divided between them.

Catalysts

Four types of catalyst are in use. The first[1] consists of platinum group metals deposited on alumina spheres or pellets. The maximum allowable bed temperature is given as 816°C (1500°F) and for each percent of oxygen in the feed gas a rise of 130-139°C (235-250°F) occurs with methane as fuel and of 150-161°C (270-290°F) with hydrogen.

The temperature required to initiate reduction is 149°C with hydrogen and 399°C with methane. The maximum temperature rise permissible is, therefore, 816 − 150°C = 666°C and this corresponds to a limit of reduction of 4.4% O_2 using hydrogen fuel.

With methane fuel the maximum bed temperature rise is limited to 816 − 399°C = 417°C and the oxygen range to $\frac{417}{130} = 3.2\%$ O_2.

Reported space velocities lie between 30,000 and 60,000 cu ft/hr/cu ft catalyst (0°C, 14.7 psig) with increase in pressure favouring the higher figure. Gas velocity is chosen to obtain a reasonable pressure drop across the catalyst bed, values of 2-3 psig being used.

Starting with tail gas containing 0.3-0.5% NO_2, residual

* Senior Chemical Engineer and Acting Project Manager with Constructors John Brown Ltd.

values of 50 ppm are claimed, and with hydrogen as the fuel to produce pure nitrogen, concentrations of the order of 5 ppm are reported.

The life of the alumina-based catalyst should be in excess of one year, but the catalyst chamber should be carefully designed to avoid abrasion from gas velocities that are too high. Temperature limits should also be strictly observed and bed temperatures are usually automatically controlled.

A second catalyst,[2] which consists of a deposit of platinum metals on ceramic pellets, has an ignition temperature of 150-200°C with hydrogen, and 400-430°C with natural gas. A maximum bed temperature of 1500°C and a residual NO_2 value of 10 ppm in the treated tail gas have been reported with this catalyst, with the space velocity at 50,000[3] and a catalyst life of between two and five years.

A Russian source reports the use of a nickel copper catalyst on a carrier at 500-600°C, claiming complete destruction of NO_2 using hydrogen as a fuel.[4]

An interesting development by an American company is all-metal construction using a deposit of precious metals (platinum, etc.) on crimped 80 Ni 20 Cr. alloy ribbon.[5] The ribbon is folded into mats which are built up into catalyst beds; these may be firmly fixed in a catalyst chamber and are also light in weight.

This construction is free from the "spalling" encountered with other types of catalyst, and since it has high conductivity and is light in weight it responds rapidly to temperature changes. This renders indication and control relatively easy. The ribbon catalyst is rated for continuous operation at 870° (1600°F), which is somewhat higher than that claimed for the pellet types.

Initiation temperature for the ribbon catalyst is 400°C (750°F) with an upper inlet temperature limit of 580°C (1060°F). Temperature rise is given as 110°C for each 1% oxygen in the feed gas. This would limit oxygen content of feed gas to $\frac{(870-400)}{110} = 4.3\%$ maximum. Space velocities of up to 120,000 are used with this catalyst.

Design of Reactors

Reactor design is dependent on space velocity, pressure drop, limiting temperature, oxygen and NO_2 in feed, fuel available, and whether the energy available is to be recovered by steam boiler, gas turbine or a combination of the two.

The volume of the catalyst will be obtained from the space velocity and the volume of gas to be treated. The diameter of the catalyst bed is calculated from the catalyst volume and permissible pressure drop. Here the ribbon catalyst results in more compact design than the pellet types.

Nitric acid plants operate according to their design, at pressures of 1-8 atm. Higher pressures result in smaller sized units per ton/day HNO_3 capacity. Space velocity of tail gas catalyst also increases with increase of operating pressure and economics favour high-pressure operation.

As previously stated, the $O_2 + NO_2$ content of the feed gas will determine the amount of fuel required to produce a colourless effluent gas. The temperature rise per cent of oxygen for the fuel used and the upper temperature limit of the catalyst will fix the operating temperature. Where the catalyst bed temperature rise would exceed this upper limit, the reduction is carried out in two stages, with intercooling usually in the form of a waste heat boiler. In such cases it is convenient to divide the catalyst into two equal parts.

Gas flow through the catalyst bed should be so directed as to avoid damage by abrasion between pellets, downhill flow being usually preferred by designers. This limitation does not, however, apply to the ribbon catalyst. To secure efficient mixing of the fuel gas and process gas streams it is desirable to sparge in the fuel well upstream of the catalyst

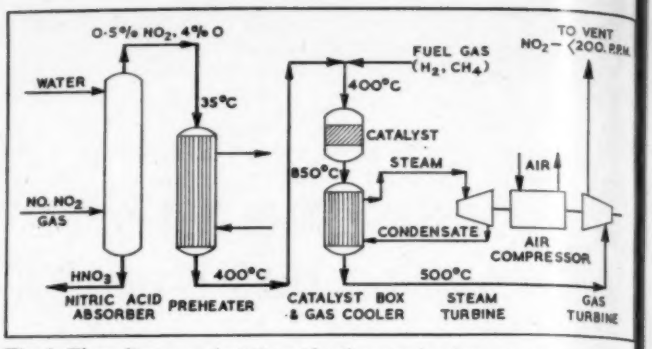

Fig. 1. Flow diagram of nitric acid tail-gas reduction process.

chamber, otherwise high local concentrations of fuel will produce hot spots in the catalyst which in turn will cause damage by spalling or melting.

Catalyst containers and supports are exposed to severe conditions of temperature, and materials of construction are therefore chosen from nickel alloys and stainless steels with good mechanical properties and resistance to creep and corrosion.

Other Design Features

The choice of means of recovering the thermal energy produced in the catalyst chamber will depend on local factors. If the nitric acid plant is part of a large chemical complex where steam is in demand, the waste heat boiler may be preferred. In the case of an independent fertiliser plant a unit self-supporting in energy requirement is possible by using both waste heat-boiler and gas-turbine.

Gas-turbine operation in this field is at present limited to inlet temperatures of 900-1100°F. As exit gases leave the catalyst at temperatures up to 1600°F some reduction is essential before they enter the turbine. This may be achieved, where power recovery is the paramount factor, but passing part of the feed gas around the catalyst so that on re-mixing the stream temperature is acceptable to the turbine.

Where both steam and power can be utilised, the practice of cooling the gases from 1600°F to 900°F in a waste heat boiler is followed. The gas turbine may then be used to drive one end of a compressor shaft, whilst the steam from the waste heat boiler drives the other.

The economics of tail gas reduction will depend on the individual factors operating at a plant, such as tail gas composition, operating pressure, whether power recovery or reduction in oxides of nitrogen is of paramount importance. For a nitric acid plant operating under pressure at 100 psig the following are approximate values. A 200 ton/day nitric acid unit with a tail gas volume of about 20,000scfm would require a catalyst charge costing, say, £5000/£7000 and a full installation of catalyst, catalyst chamber, waste heat boiler, piping and controls would cost between £50,000/£75,000 according to specific requirements.

The use of catalytic combustion for the removal of offensive material in process gases is a recent development and experience is still being accumulated by designers and operators. There seems little doubt that under the impetus of clean air legislation the field of application will broaden and the application described here illustrates only one choice out of a wider range of possibilities. In our densely populated island such contribution to the improvement of atmospheric conditions in industrial areas will no doubt be universally accepted.

REFERENCES
[1] Baker Platinum Division, Engelhard Industries Ltd.
[2] Girdler Catalysts, Louisville, Ky., U.S.A.
[3] *Chemical Engineering*, January, 1959.
[4] *Zhur. Priklad. Khim.*, 31, 1958.
[5] *Catalytic Combustion Corporation*. B.P. 775,549 and 775,550.

66.047.791

SPRAY DRYING OF PIGMENT SLURRIES

Use of spray drying is extending to materials hitherto dried by other methods. This article describes work carried out with a single fluid atomiser drier of unconventional design

by Ing. G. KIRÁLY*

ATOMISATION in stationary single-fluid nozzles is obtained by forcing the liquid under high pressure through small orifices, a swirling motion being imparted to the liquid by virtue of the shape of the nozzle.

In the following simplified analysis of the action of the hollow cone spray nozzle, the motion of the liquid may be considered to be caused by two components of velocity, one axial and the other rotational.

As a result of the rotary motion, a liquid annulus is created in the tube of outside diameter $2r$ and inside diameter $2a = 2r\varphi$. According to data taken from the literature, φ has a value of 0.8. The area cross-section of the liquid is then $\pi r^2 (1 - \varphi^2)$, and if V m^3 sec.$^{-1}$ is the amount of liquid discharged in unit time, then the axial flow rate is

$$v_{ax} = V/\pi r^2 (1 - \varphi^2) \text{ m/sec.}$$

If in the 90° eddy area of the sprayer, the peripheral velocity at the wall of the conical section is assumed to be constant, then the feed rate, v_b, should be equal to the tangential outlet rate v_t. The tangential discharge rate is given by:

$$v_t = v_b^{\frac{1}{2}} = \left(\frac{4V}{a^2\pi}\right)^{\frac{1}{2}}$$

where a is the diameter of the inlet orifice.

The centrifugal force C and the power N_t can be calculated from the tangential outlet rate:

$$C = \frac{V\rho}{gt} \cdot \frac{v_t^2}{(\varphi + 1)r/2}$$

$$= 2V\rho\, v_t\, \pi/g \text{ kg}$$

whence $$N_t = Cv_t = 2V\rho\pi\, v_t^2/g \text{ m kg sec}^{-1}$$

From the definition of surface energy, the energy required to produce the new surface established by the atomising nozzle

$$\simeq 6\sigma/\rho_l d$$

per unit mass flow rate of liquid where d is the surface mean diameter (diameter of drop whose specific surface is equal to that of the entire spray), σ is the liquid surface tension, kg m^{-1}, and ρ_l is the liquid density in kg/litre. If the

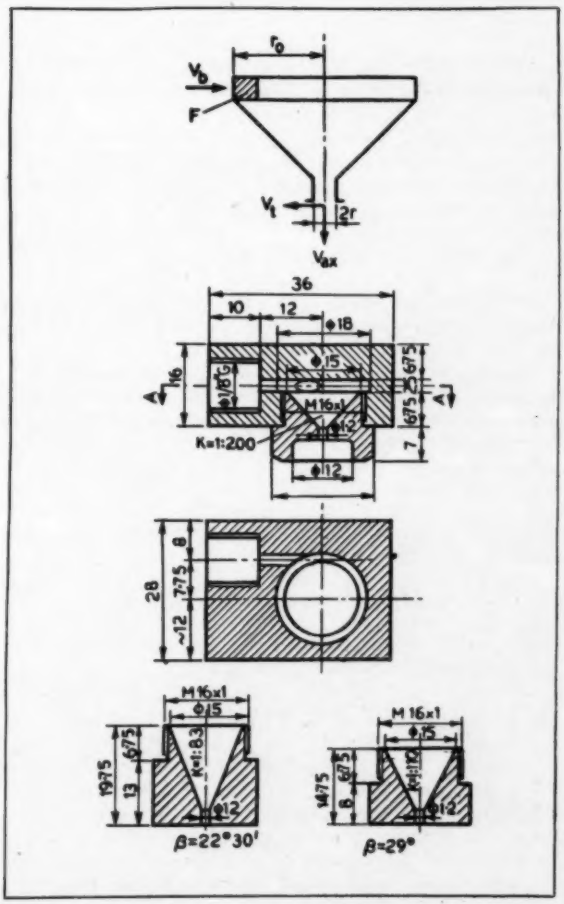

Fig. 1. Diagram of high-pressure spray nozzle with details of nozzles used in tests. (Dimensions in mm.)

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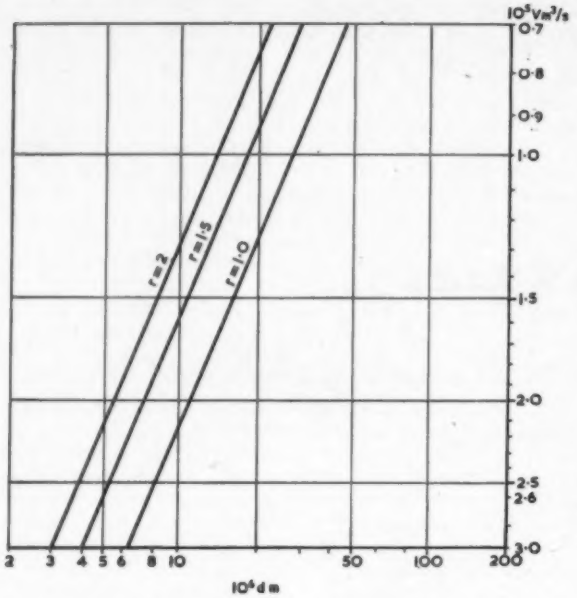

Fig. 2. Drop diameter atomiser throughput and fluid specific gravity relationship.

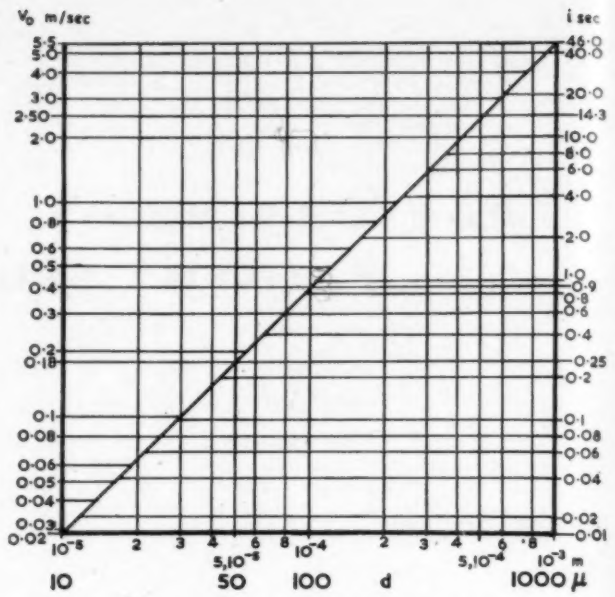

Fig. 3. Chart for determining drying period, given drop diameter and settling velocity.

atomising is considered to be due entirely to the rotational motion of the liquid, then:

$$N_t = 6\sigma V/d$$

For an atomising nozzle of given diameter, a relationship between the values of drop diameter and nozzle output can be obtained from the expressions for the tangential effect and from the tangential outlet rate:

$$\frac{3\sigma}{d} = \frac{\gamma\pi}{g}\left(\frac{4V}{a^2\pi}\right)^{\frac{4}{3}}$$

For the nozzles of Fig. 1, this relation is shown by Fig. 2. When $V = 10$ ml/sec. (10^{-5} cu m/sec.), the minimum drop diameter is approximately 18 μ.

Let the varying axial rate of the drop be denoted by v, the value of which decreases during the elapse of time t_0 along the distance s_0, from the initial value of $v_0 = v_{ax}$ to zero. Then:

$$c\ \frac{v^2\,\rho_l\,d^2\,\pi}{2g\,.\,4} = -\frac{d^3\,\pi\,\rho}{6g}\,\frac{dv}{dt}$$

where the negative sign refers to rate decrease. According to Allen, the value of constant c is

$$c = 18.5\ \mathrm{Re}^{-0.6}, \text{ where } \mathrm{Re} = \frac{v_0 d}{\nu} = \frac{v_0 d\,\rho l}{\mu}$$

where ν is the kinematic viscosity in $m^2\ sec^{-1}$ and μ is the dynamic viscosity in kg m^{-1} sec^{-1}.

On substituting, separating the variables and integrating between the velocity limits, we obtain:

$$-\int_{v_{ax}}^{0}\frac{dv}{v^{1.4}} = 13.9\,\frac{\nu^{0.6}\,\rho_l}{d^{1.6}\,\rho}\int_0^{t_0} dt$$

and

$$2.5\ v_{ax}^{-0.4} = 13.9\,\frac{\mu^{0.6}\,\rho_l}{d^{1.6}\,\rho}\,.\,t_0$$

From this, the time to decelerate to zero velocity is:

$$t_0 = 0.18\,\frac{d^{1.6}\,\rho}{\mu^{0.6}\,\rho_l}\,.\,v_{ax}^{-0.4}$$

For drops of 18 microns in diameter and for nozzles of the dimensions shown in Fig. 1A, we obtain for v_{ax} the value of 35.2 m/sec.; taking $d = 50\ \mu$ and $\mu/\rho = \nu = 1.3\ 10^{-5}$ m/sec., the value for t_0 is thus $= 5.63\ 10^{-3}$ sec. Finally, assumed that the deceleration of the drop is constant, the distance travelled before it comes to rest is 99 mm.

A Spray Drying Problem

The following is a typical problem. A thick flowing, aqueous suspension of a specific gravity of 1.5 to 2.0 kg/l is to be prepared from a pulverised mineral of a specific gravity of 5.7 to 6.9 kg/l and dried by spraying into a direct-current hot air flow stream. The required output of an experimental sprayer with an atomising pressure of 6 atm was 0.036 cu m/hr or 54 kg/hr of slurry. Since the slurry contains 60% by weight of water, 32.4 kg/hr of water were to be evaporated in order to obtain a residue of 21.6 kg/hr of dry pigment powder. This output corresponds to that of a large-scale laboratory experiment.

Required:

(a) heat requirement of the drying process;
(b) temperature limits;
(c) velocity of drying air;
(d) quantity of drying air;
(e) duration of the drying period;
(f) diameter of the sprayed drop;
main dimensions of the equipment.

The heat required for the evaporation is 5.5 kcal/sec. If the air used for drying is at 200°C and is cooled to 120°C, 0.226 N cu m/sec. of air are required. At the mean operating temperature of the plant, this is equivalent to 0.358 cu m $sec.^{-1}$ of air.

The diameter of the drying column was fixed as 300 mm. Hence the mean air velocity is 5.04 m/sec, and the residence time of air in the column is 0.8 sec.

For the determination of drop diameter, the knowledge of the period of drying of the drops is required, which, in turn, requires knowledge of the rate of surface heat transfer.

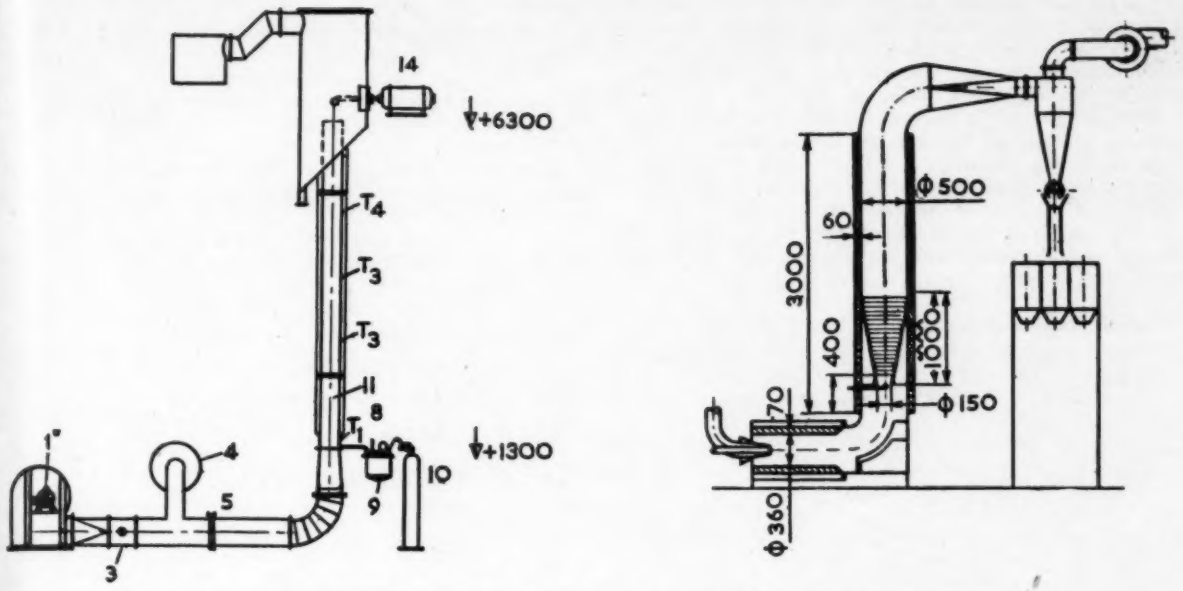

Fig. 4. Experimental spray drier and proposed layout of large-scale spray drier.

As this latter is a convective process, the settling velocity of drops must be determined.

The limiting settling velocity v_0 can be obtained from

$$c \frac{v_0^2 \rho_l}{2g} \cdot \frac{\pi d^2}{4} = \frac{\pi \rho d^3}{6}$$

where resistance factor c for the Reynolds numbers of $4 < Re < 400$ is given by

$$c = 18.5\ Re^{-0.6}$$

Substituting, and solving for v_0, gives

$$v_0 = \left[\frac{8}{111} \frac{d^{1.6} \rho g}{\rho_l \mu^{0.6}}\right]^{0.715} \text{ m sec.}^{-1}$$

The convective heat-transfer rate can now be determined by the expression given by Kudriashev.

$$\frac{hd}{k} = 2 + 0.33\ Re^{0.5} \text{ kcal/m}^2 \text{ hr °C*}$$

where $$k = 0.02 \left(\frac{T}{T_0}\right)^{\frac{1}{2}} = 25.2\ 10^{-3} \text{ kcal/m hr °C}$$

For determining the period of drying, the weight of water per unit surface of drop is required:

$$W_0 = \frac{0.6\ \pi d^3 \rho}{6 \pi d^2} = 150\ d \text{ kg m}^{-2}$$

Since the heat needed for heating the dry substance can be neglected, the total heat requirement can be considered as heat of evaporation. In this case, the period of drying can be calculated from

$$t = \frac{W_0\ 600}{h\ .\ \triangle t} 3600 \text{ secs}$$

From the settling velocity and the drying period relationships one finds that their logarithms are each proportional to log drop diameter. This is expressed graphically in Fig. 3, which allows drying period to be estimated rapidly, given the values of the remaining variables.

Thus drops of 95.10^{-6} m diameter, i.e., 95 μ, can be dried in the proposed column, but this cannot be said of particles of greater diameter. The particles of the above size have a drying period of 0.85 sec, and a settling velocity of 0.38 m/sec. Hence, since the air velocity is 5.04 m/sec the actual particle velocity is $5.04 - 0.38 = 4.66$ m/sec, consequently the residence time is $4/4.66 = 0.86$ sec, which is in fair agreement with the value of 0.85 sec obtained from Fig. 3. Since particles of a diameter less than the limiting value are to be sprayed, the dimensions selected for the column are satisfactory.

The total heat required for raising 0.358 cu m/sec of drying medium from 10°C to 200°C is 56,000 kcal/hr.

Experimental Spray Drying

Drying experiments were carried out in the equipment shown in Fig. 4. The spraying and drying operations were conducted in a column of 300 mm inner diameter and 5 m overall height (11). In order to minimise heat losses and adhesion to walls, the column was thermally insulated over its entire surface. The column outlet is attached by a knee joint to a horizontal pipe section, which latter includes an orifice (5) for measuring the flow rate of drying air. Before the horizontal pipe section, a blower for secondary air (1) is installed, the output of which can be controlled within broad limits by the butterfly valve (3) located on the suction side. The flue gas duct of the combustion chamber (4) heats the air for drying, and is connected with the horizontal pipe section. The amount of fuel was measured by the orifice flowmeter (7), the primary air for combustion was supplied by fan (2), the pressure pipe of which was equipped with another metering orifice (6).

The atomiser was fixed to the end of a rigid inlet tube (8) in the centre line of the column. In order to allow the spray to be observed, a mica window was located in the wall of column, on the same level as the sprayer. The slurry was introduced into the nozzle through a jacketed container (9), equipped with two outlet connections, one of which was attached to the sprayer and the other, through a pressure control valve, to the pressure source nitrogen cylinder (10).

The gas inlet tube (11) projected deeply into the container in order to attain a fair admixture of pressure gas to the slurry and to avoid sedimentation. To heat the slurry, it was possible to switch the jacket of the container to the gas mains, and sedimentation chamber (12) was located in the upper part of the column for collecting the dried substance. From this chamber, the drying medium left the system through a water seal (13). Sampling was carried out with the use of a fan (14) with an output of 70 cu m/hr, which proved adequate for this purpose.

Dimensions of the nozzle are shown in Fig. 1A and the value of φ determined from the pressure drop and throughput came to 0.49.

The Results of Experimental Spray Drying

Samples of dried pigment powders produced in this drier contained 0.1 to 0.4% of moisture. Sedimentation tests proved that 65 to 78% of the samples consisted of particles of diameter below 20μ.

From the measurements made, the heat balance of the process was as follows:

Heat of drying and heat losses of the insulated column	24,400 kcal/hr
Heat loss due to drying medium ...	43,400 kcal/hr
Heat loss due to uninsulated pipeline	10,700 kcal/hr
Heat loss of combustion chamber ...	5,300 kcal/hr
Total heat used	83,800 kcal/hr

Hence 24,400 kcal/hr were utilised of the total heat investment of 83,800 kcal/hr, corresponding to a thermal efficiency of 29%.

Summary

Of the possible modern methods, the spray-drying process appears to be well suited for the drying of pigment slurries.

It was found that all the pigment slurries subjected to drying could readily be sprayed by the technique evolved for moisture contents in excess of those reported for the experiments.

The temperatures applied and the impurities of the drying medium did not reduce the quality of the pigment powder produced.

The pressure atomiser used in the spray drier proved to be suitable for a pressure of 6 atm. On adequately adjusting the conditions of spraying, it was often possible to produce dry powders of particle sizes which made the subsequent disintegration of the product unnecessary.

BIBLIOGRAPHY

Baunack and Rammler: *Freiberger Forschungshefte* A 50.

Bruniak, R., and Magyar, F.: *Radex-Rundschau*, 1952, 120-3.

Comings, E. W., and Coldren, C. L.: *Chem. Engng. Progress*, **53**, 231-6, 1957.

Crosby, E. J., and Marshall, W. R., Jr.: *Chem. Engng. Progress*, **53**, 347-52, 1957.

Duffie, J. A., and Marshall, W. R. Jr.: *Chem. Engng. Progress*, **49**, 417-23 and 480-6, 1953.

Fraser, R. P., Eisenklam, P., and Dombrowski, N.: *Brit. Chem. Engng.*, **2**, 414-17, 496-501, 538-43 and 610-13.

Marshall, W. R., Jr.: *Transactions of the A.S.M.E.*, **77**, 1377-85, 1955.

Marshall, W. R., Jr.: *Atomisation and Spray Drying*, American Institute of Chemical Engineers, Cleveland, 1954.

McLair, H. A., Comings, E. W., and Nyers, J. E.: *Chem. Engng. Progress*, **53**, 282-9, 1957.

Taylor, E., and Harmon, D.: *Ind. Engng. Chem.*, **54**, 1455, 1954.

Troesch, H. A.: *Chem. Ing. Tech.*, **26**, 311-20, 1954.

Ziegler, L.: *Chem. Ing. Tech.*, **29**, 466-8, 1957.

Cryogenics—A New Journal of Low-temperature Engineering and Research

A NEW publication, devoted exclusively to the realm of low-temperature engineering and research, has just been launched by Heywood & Co. (London and New York), the publishers of BRITISH CHEMICAL ENGINEERING.

The new publication, called simply "Cryogenics", will appear quarterly and its contents will consist of original papers covering all fields of cryogenic science and technology together with brief technical notes, correspondence, book reviews and a bibliography listing all the important papers and articles in this important sphere. Another feature of the journal is the abstracts of the papers which appear in English, French, German and Russian.

International Panel of Editors

The new journal is being produced under the joint editorship of Dr. KURT MENDELSSOHN, F.R.S., of the Clarendon Laboratory, Oxford; R. B. SCOTT, chief of the N.B.S. Cryogenic Engineering Laboratory, Colorado; and Professor L. WEIL, of the Institut Fourier, Grenoble University. In addition, a panel of twelve experts resident in Australia, Belgium, Canada, Czechoslovakia, Germany, Holland, India, Israel, Italy, Japan, Sweden and Switzerland act as advisory editors.

Among the topics dealt with in the current issue are a Joule-Thompson helium liquefier and some problems on the design of such liquefiers. In this paper its author, D. H. PARKINSON, of the Royal Radar Establishment, Malvern, Worcs., gives details of a helium liquefier which uses liquid hydrogen and liquid nitrogen as the refrigerating media; the aspects of design and operation discussed include the heat exchange system, the hydrogen bath conditions and the handling of liquid helium. The paper also focuses attention upon unusual aspects of design, such as the use of the Collins and space-wound cross flow exchangers above the liquid nitrogen and liquid hydrogen baths.

Heat Transfer through Evacuated Insulants

Also included in the issue is a paper dealing with recent improvements in low-temperature insulants. Its authors, A. H. COCKETT and W. MOLNAR, of British Oxygen Research & Development Ltd., London, examine theoretically the modes of heat transfer through evacuated insulants, an analysis which they apply to experimentally determined thermal conductivities in order to separate the heat transferred by conduction from that transferred by radiation. One of the insulants shown to possess low thermal conductivity consists of aluminium foils separated by mesh material.

From the Clarendon Laboratory, jointly with A.E.A., Harwell, appears a paper dealing with the effect of radiation on thermal conductivity of superconductors. This paper, written by K. D. CHAUDHURI, K. MENDELSSOHN and M. W. THOMPSON, reports the effect of neutron irradiation on the thermal conductivity of niobium and vanadium single crystals at low temperatures. The measurements were carried out in both superconducting and normal states where conduction is due mainly to phonons and electrons respectively.

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DIFFUSION IN DILUTE SOLUTIONS —A NEW CORRELATION

A simple method of estimating liquid diffusion coefficients makes use of a modified Schmidt group

by S. H. IBRAHIM and N. R. KULOOR*

THE diffusion coefficient appears as an important variable in the quantitative treatment of mass transfer in liquid systems. Mass transfer in absorption solvent extraction, distillation and other diffusional operations need basic data. The role of diffusion coefficients in various diffusional operations has been discussed by Sherwood and others.[8] The diffusion data are meagre in the literature and are not available for many systems encountered in chemical engineering operations.

No completely theoretical equations for estimating the diffusion coefficients are available in the literature. In the absence of reliable experimental data and a useful theoretical approach, one has to make use of dependable generalisations which permit the solving of each individual problem. Thus empirical and semi-theoretical methods of estimating physical properties play an important role in design calculations and for many other purposes in chemical engineering and applied science[7]; Eyring, Arnold, Othmer and Thakar[3, 2, 5] have advanced semi-theoretical and empirical equations towards this direction.

Of the equations developed, those of Wilke[10] seem to be the most suitable and useful; the present article deals mainly with his method and discusses the reasons for advancing yet another correlation on this subject.

The main short-coming of the earlier correlations is that they are represented by fairly complicated equations. Moreover, sufficient data are not available for general application of these methods. There is a strong case for an empirical equation, with variables for which data are readily available. Accordingly, a simple equation for the diffusion coefficient of the liquid systems has been deduced from the knowledge of the molecular nature of a given system.

Discussion

From the Stokes Einstein equation[10] and the theory of the interdiffusion of dissimilar molecules[9] it can be seen that the primary variables of diffusion coefficients are the shape and volume of the solute particles. The effect of molecular size on diffusion is discussed by Powell and co-workers.[6] In an attempt to utilise these findings, Wilke[10] has defined a number called $F = \frac{T}{D\mu}$, which he has plotted against molecular volume and which he uses in his empirical equation. In a later modification he has introduced a solvent factor[11] which improves the utility of the equation. In the present paper we have attempted to explain the appearance of this factor in these equations.

Symbols Used

D = diffusion coefficient, cm²/sec;
M = molecular weight of solute;
V_m = molecular volume of solute;
φ = viscosity, poise;
$N'_{sc} = \frac{\mu V_m}{D}$ modified Schmidt number;
$N_{sc} = \frac{\mu}{\rho D}$ = Schmidt number;
T_c = critical temperature;
T_r = reduced temperature; and
T_b = normal boiling point.

Molecular diameter is numerically equal to the cube root of the molecular volume of the liquid at its boiling point. And on the micro-scale the viscosity reflects the effect of molecular motions and interaction. If these two properties are taken into consideration, it can be claimed that the important variables of diffusion—namely, the shape and the volume of solute molecules—have been introduced. This is the basis for Wilke's development. But in our opinion viscosity alone is not sufficient to bring out the effect of inter-atomic distance. As molecular weight is closely associated with the molecular diameter and volume, we consider it worthwhile to introduce this factor into the correlations already available for this purpose, along with molecular volume and viscosity, and then to see how far it correctly represents the data. For this purpose liberal use has been made of the data presented by Wilke, Othmer and Thakar and Arnold (loc. cit.).

In order to introduce the molecular weight into the picture we have suggested a new dimensionless number, $\frac{\mu V_m}{D}$.

As this number is quite similar to Schmidt number, we can refer to it as a modified Schmidt number (N'_{sc}). The

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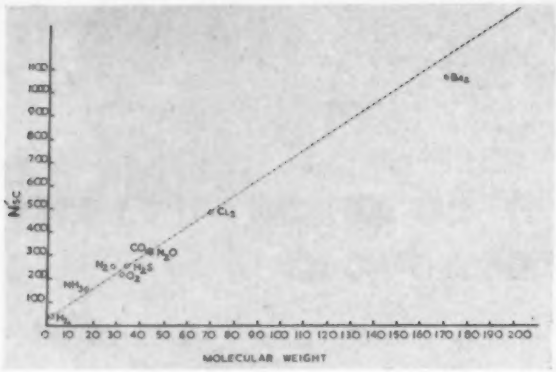

Fig. 1. Diffusion of inorganic gases in water.

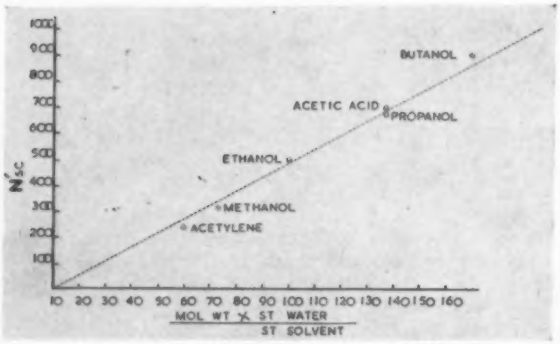

Fig. 2. Diffusion of organic gases in benzene.

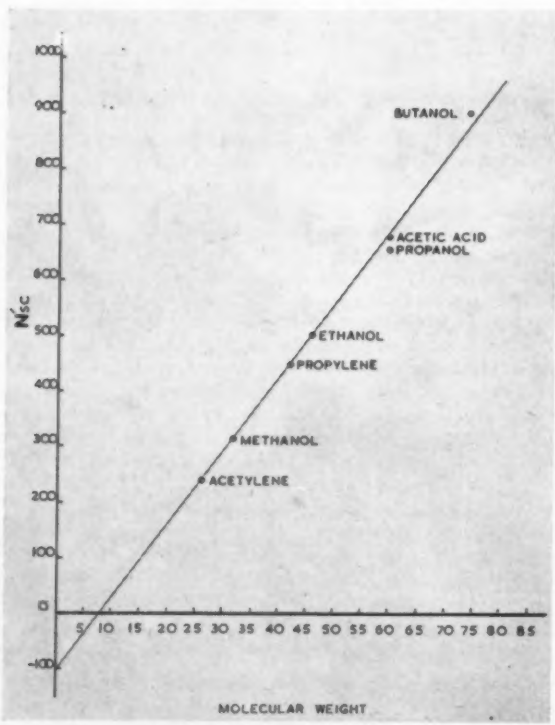

Fig. 3. Diffusion of organic gases in water.

experimental values are used for viscosity and diffusion coefficients. For determining molecular volume, Kopp's law of addition is used based on the available values of atomic volumes, as was done by Arnold[3] and Gilliland.[4] For various organic and inorganic gases the values of viscosities are calculated in the absence of experimental values by Arnold's equation.[1] Even for the liquids the viscosities are taken only in gaseous state. For various compounds whose molecular weight ranges from 2-120, the N'_{80} values are calculated and plotted against molecular weight. This gives straight-line curves [Figs. 1 and 2 (a) and (b)] with different slopes for organic and inorganic compounds. From these curves an empirical equation of the form shown later is derived and various diffusion coefficients were checked for these two broad classifications, viz., organic and inorganic. The values thus obtained remarkably coincide with experimental values with some exceptions; wherever the experimental values are substituted in the equations, good agreement has been obtained. But in general the average error falls within 10% (Tables I and II). Considering the fact that the available data on diffusion coefficient are meagre, this method appears to be potentially useful, its simplicity being a feature much in its favour. Since the molecular volume can be easily obtained by Kopp's Law, one factor only is required —viscosity of the solute in the gaseous state—to obtain the diffusion coefficient.

Diffusion in Solvents other Than Water

In liquids the molecules are very close together and are continually within the range of attractive and repulsive fields of force of neighbouring molecules. The molecules in the interior of liquids are attracted equally in all directions by their neighbours. In liquids X-ray diffraction reveals a more or less orderly arrangement of molecules in small groups. And there is no evidence that there is any organised structure of molecules in the surface of a liquid. In the interior of a liquid there is no continuing force on molecules in any direction. At the surface of a liquid, however, there is practically no force attracting the surface molecules away from the liquid. This leads to an unbalanced inward attraction on the surface of the molecules. A surface possesses a definite quantity of potential or free energy. Surface tension or free surface energy is due to this inward unbalanced attraction on the surface molecules.

We believe that for a gas to diffuse into this liquid a certain amount of extra work has to be done to break through the extra energy barrier due to this surface. Once the gas penetrates this barrier, the diffusion coefficient defines exactly the work it has to do to pass into the liquid molecules in the interior of the liquid. This extra work to break the surface barrier is the characteristic of the solvents. Taking water as the reference substance, the ratio of surface tension of solvent to water represents the relative energy requirement. As the surface tension itself defines this energy due to the surface, N'_{80}, is multiplied by the function

$$\varphi = \frac{\text{Surface Tension of Water}}{\text{Surface Tension of Solvent}}.$$

$\varphi\ N'_{80}$ values are plotted against the molecular weight or N'_{80} is plotted against

$$\text{(Molecular weight)}\ \frac{\text{(Surface Tension of Water)}}{\text{Surface Tension of Solvent}}.$$

The latter method of plotting is to be preferred as it avoids the carry-over of errors in N'_{80}. From these plots an empirical equation is evaluated and used for checking the diffusion coefficients; each solvent requires a new equation which is similarly obtained. The above reasoning was checked for the diffusion coefficients in benzene. Work is in progress to study its application to other solvents.

TABLE I—Inorganic Gases
Temperature 25°C

No.	Gas	*M*	*Vm*	Poise	N'sc	*D* × 10^{-5}	
1	CO_2	44	34	15 × 10^{-5}	320.0	1.70	E
2	H_2	2	14.3	8.8 × 10^{-5}	37.45	3.36	E
3	NH_3	17	25.8	10.0 × 10^{-5}	152.00	1.76	E
4	N_2	28	15.6	17.0 × 10^{-5}	255.0	2.0	E
5	HCl	36.45	30.6	15.6 × 10^{-5}	180.0	2.64	E
6	H_2S	34	28.4	13.0 × 10^{-5}	252.0	1.41	E
7	N_2O	44	36.4	13 × 10^{-5}	315.0	1.51	E
8	O_2	32	25.6	20 × 10^{-5}	215.0	2.40	E
9	Cl_2	70	48.4	14.0 × 10^{-5}	484.0	1.40	E
10	Br_2	159.8	53.2	17 × 10^{-5}	1020.0	0.90	E
				From the equation:			
11	SO_2	64	40.4	12.5 × 10^{-5}	—	1.30	OT
						1.52	T
12	PH_3	34	38.1	10.8 × 10^{-5}	—	1.60	OT
						1.70	T
13	CS_2	76	66.0	9.6 × 10^{-5}	—	1.14	OT
						1.24	T
14	HI	128	40.7	18.5 × 10^{-5}	—	1.51	OT
						0.90	T
15	HBr	80	30.7	18.2 × 10^{-5}	—	1.80	OT
						1.20	T

OT — Othmer.
T — This work.
E — Experimental.

Note: The halogen gases HCl, HBr and HI are not in agreement with this correlation.

TABLE II—Organic Gases
Temperature —25°C

No.	Substance	*M*	*Vm*	μ × 10^{-5}	N'sc	D Water × 10^{-5}	*D* Benzene × 10^{-5}	
1	Methanol	32	42.5	9.5	315	1.28	2.869	
2	n-propyl alcohol	60	81.4	7.0	655	0.87	1.60	E
							2.00	T
3	Acetylene	26	37.0	10.0	240	1.56	—	
4	Acetic acid	60	68.4	9.0	676	0.91	1.92	E
							2.07	T
5	Ethyl ether	74	97.6	7.55	—	No data	2.21	E
							1.95	T
6	Ethanol	46	59.2	8.50	503	1.00	—	
7	Propylene	42	66.6	8.00	444	1.20	—	
8	Chloroform	119.5	95.3	11.00	—	—	2.11	E
							2.00	T
9	Butyl alcohol	74.0	103.6	7.00	930	0.77 W	—	
						0.84 T		
10	Chlorobenzene (40°C)	112.5	115	8.10	—	—	1.85	W
							1.84	T
11	Ethyl acetate	88	108.6	6.4	—	—	2.40	W
							1.90	T
12	Ethyl bromide	109	79.6	10.4	—	—	2.18	W
							1.75	T
13	Cyclohexane	84	118.2	6.4	—	—	1.50	W
							1.80	T
14	Acetonitrile	41	52.7	11.8	—	—	3.0	W
							3.3	T
15	Methylene chloride	85	65.4	10.34	—	—	2.00	W
							1.82	T
16	Methyl chloride	50.5	47.5	12.00	—	—	3.00	W
							2.60	T
17	Acetone	58	74.0	7.40	—	—	2.31	OT
							2.25	T
18	Acetaldehyde	44	51.92	9.06	—	—	2.80	OT
							2.50	T
19	Bromobenzene	157	118.9	9.00	—	—	1.56	T
							1.80	E
20	Nitrobenzene	123	117	10.00	—	—	1.84	E
							2.00	T

W = Wilke
T = This work.
OT = Othmer.
E = Experimental.

Procedures for Calculating Coefficients

(1) Diffusion coefficient of inorganic gases in water

Calculate the N'sc for known values of *D*. Plot against the molecular weight or use the equation $\frac{\mu V_m}{6.5M+30} = D$.

(2) *(a) Diffusion coefficient of organic gas in water*

Plot N'sc against molecular weight for known values of *D* or use the equation $\frac{\mu V_m}{13M-100} = D$.

(2) *(b) Diffusion coefficient of organic gases in benzene*

Plot N'sc against

$$\text{(Molecular weight)} \cdot \frac{\text{(ST of Water)}}{\text{(ST of Solvent)}}$$

for known values of *D*, or use $\frac{(\mu V_m)}{(4.5M)} = D$.

Accompanying Tables I and II and Graphs 1 and 2 (a) and (b) illustrate the method:

$$\theta = \frac{T_b}{T_c}$$

Equation used for calculating gaseous viscosity:

$$\mu^\circ = \frac{0.00270M^{\frac{1}{2}}\,T_c^{\frac{1}{2}}}{V_m^{\frac{2}{3}}} \cdot \frac{T_r^{\frac{1}{2}}}{T_r + 1.47\theta}$$

REFERENCES

[1] Arnold, J. H. *J. Chem. Phy.*, **1**, 170 (1933).
[2] Ibid. *I. & E. C.*, **22**, 1091 (1930).
[3] Eyring. *J. Chem. Phy.*, **4**, 283 (1936).
[4] Gilliland. *I. & E. C.*, **26**, 681 (1934).
[5] Othmer, D. F., and Thakar, M. S. *I. & E. C.*, **45**, 589 (1953).
[6] Powell, R. E., *et al. I. & E. C.*, **33**, 434 (1941).
[7] Reid and Sherwood. "Properties of Gases and Liquids", McGraw-Hill (1958).
[8] Sherwood, T. K. *et al. Trans. Am. Inst. Chem. Engrs.*, **36**, 21 (1940).
[9] Taylor. *J. Chem. Phy.*, **6**, 331 (1938).
[10] Wilke, G. R. *Chem. Eng. Prog.*, **45**, 220 (1949).
[11] Wilke, G. R., and Chang, P. *A.I.Ch.E. J.*, **1**, 264 (1955).

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COST ESTIMATING OF PROCESS PLANTS

by M. STOGENS

MAKING decisions on capital expenditure is one of the most exacting of managerial tasks, and when a new process plant is under consideration, the cost-estimate can be the most important factor affecting the decision, whether to build or not to build! The more careful the preparation of the cost-estimate and more details it provides, then the better the chance the new project has of going forward. Detailed cost-estimates give managements confidence; on the other hand when an estimate is not based upon up-to-date construction costs of the projected new plant but contains instead many "guesstimates" and at the same time allows large sums for contingencies, it is not likely to inspire confidence.

Through lack of adequate cost data, many new processes may be abandoned as "uneconomic" simply because a false impression of their capital costs has been given.

It is regrettable that some chemical engineers are not exceptionally cost-minded, and often have little idea of realistic costs. What must be grasped is that managements require reliable cost-estimates solely, because not only are they essential to sound investments, which must yield a high return on capital with the minimum of risk, but they also affect the future welfare of a company.

It can be said that good cost estimates lead to disappointment before the money is spent, rather than afterwards; they avoid future trouble.

For a management the return on the capital is of major importance, for it reveals the attractiveness of the investment; this can be expressed as the ratio of the total amount stated in the cost-estimate to the profit expected.

When a management is considering the erection of a new plant, commercial competition may demand an early decision. Therefore cost estimates too must be produced quickly. This means having at hand up-to-date costs of all types of plant and equipment as well as maintenance and labour costs.

In this early stage detailed drawings are not available. Accurate cost estimates require a flowsheet with sized equipment, number, types and other details plus price lists, tables and graphs of prices for all types of equipment. It is good practice to record all the costs that one can, bearing in mind, that once prices for pumps, compressors, drives, drums, distilling towers, extruders, weighing scales, blenders, hoppers, fans, heat exchangers, boilers, heaters and so on have been accumulated, that there are some other costs which although only minor to the process, are important to the total capital costs.

When the prices of the process equipment are known, an allowance must be made for structural steel work, piping insulation, painting and other facilities and the erection costs. The following are average percentage allowances to be added to the total process equipment cost:

Piping and valves	50%
Insulation	10%
Foundations	5%
Instrument building, pump house ...	10%

TABLE I—Costs of Completely Installed Process Equipment

Costs of additional materials, erection costs and indirect costs.
Expressed as percentages of process equipment costs.

Costs of process equipment	Distillation Towers 100%	Process Vessels 100%	Exchangers 100%	Pumps 100%	Compressors 100%	Instruments 100%	Miscellaneous Equipment 100%
Additional materials:							
Piping	50	60	45	30	20	40	15
Foundations, site work, paving	10	10	10	10	10	5	10
Buildings	—	—	—	20	15	10	10
Painting, cleaning, fireproofing	5	5	5	3	3	2	3
Insulation	20	10	15	7	7	3	7
Steel structures, temp., foc.	20	25	25	3	3	10	10
Electrical & Miscellaneous	5	5	5	27	12	20	15
	110	115	105	100	70	100	70
Total process equip. and materials	210	215	205	200	170	200	170
Total erection costs	110	95	85	80	60	80	60
Total equipment, materials and erection	320	310	290	280	230	280	230
All indirect costs	80	80	80	80	70	80	70
	400	390	370	360	300	360	300
Ratio: $\frac{\text{Total installed costs}}{\text{Process equipment cost}}$	4	3.9	3.7	3.6	3	3.6	3

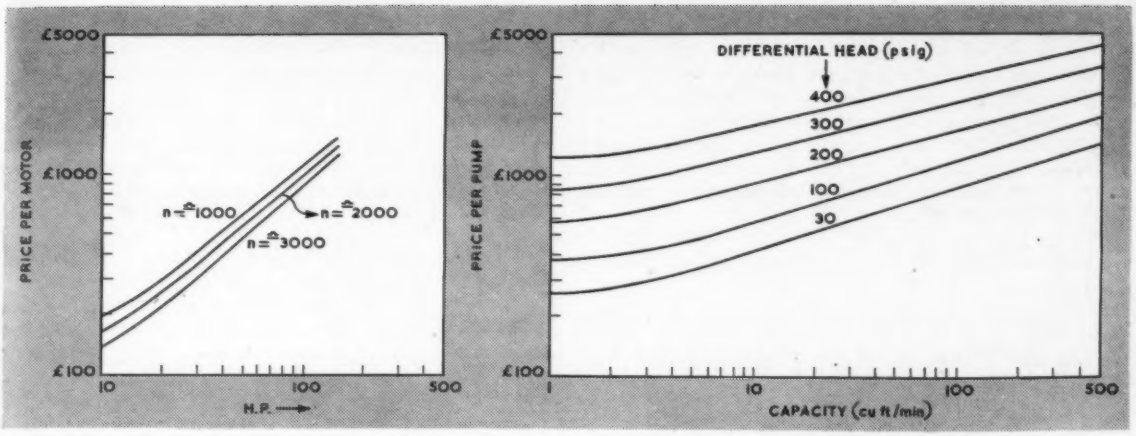

Fig. 1. Prices of electric motors (explosion/flame-proof).

Fig. 2. Prices of centrifugal pumps (cast steel/cast iron).

Structures	5%
Fire proofing	1%
Electrical	5%
Painting and Cleaning	1%

For erection 50% of the total job price should be added.

However, correlation factors (discussed later in this article) are required to take care of constructions in special materials such as Monel and stainless steel. In particular, labour costs are often underestimated; the following are some contractor costs for site labour per 57 hr week.

	Hour
Foreman	8/0
erectors	6/0
welders	6/0
chippers	5/6
helpers	4/11
labourers	4/10

For living-out 10/- per day should be allowed. Also there must be added costs for: transport, insurance, overheads, engineering and several other indirect expenses and a percentage for contingencies and price increases.

The modern trends of automatic control results in plants that are very expensive. As instrumentation forms an important item in the cost estimate it is preferable to estimate instrumentation costs separately. For quick estimates, when detailed cost data on instruments are not available, the method described in a previous article may be used.[1]

Before a new plant is built, other important questions have to be considered, e.g. the cost of production, operation and maintenance, the life of the plant, erection time, location of the new plant, economic breakpoint and priority as many processes are developed.

For cost estimates the erection time is of importance owing to the rise in prices. At present the following escalation factors can be applied: erection time 2 years, escalation will be 5%, for 3 years as high as 7% and for 4 years about 10%.

For some chemicals, e.g. ethylene, more than one production method is possible. Therefore it will be necessary to produce separate cost estimates corresponding to each route. The plant which will be chosen will be the one which cost-estimating and other considerations indicate to have the highest economy and efficiency at the minimum cost.

An economic picture of a process is often required at a very early stage, often before the flowsheets have been completed.

Complete Plant Estimates

Nine out of ten complete estimates turn out to be underestimates through failure to take into account materials which must be used with the process materials in order to provide the complete plant. The same applies to erection costs and overheads. Some engineers regard ancillaries as being of minor importance, and they consequently overlook them.

In practice it is difficult to determine prices for equipment not shown on the flowsheets, which as a rule show only the major process equipment. For example large pipelines are illustrated by lines only, sometimes only by dotted lines, a preliminary flowsheet also gives no indication about buildings, foundations, steel structures and supports, electrical equipment, insulation, temporary facilities, paving, piling (if necessary) and so on; yet all such items are important.

There are several methods of preparing the final capital cost of chemical plant. Thus when the costs of the process equipment are known multiplying factors can be used. Factors for some types of equipment are listed below.

Fob Price	*Multiplying Factor for Total Installed Costs*
Distribution Towers	4.0
Process Vessels	3.9
Exchangers	3.7
Pumps	3.6
Compressors	3.0
Instruments	3.6
Miscellaneous Equipment	3.0

How these multiplying factors were obtained is shown in Table 1.

In this table we see the average percentage for the additional materials, while we have stated the process equipment costs are 100%. Also given are the percentages for erection costs and overheads, but contingencies, which depend on several factors, are not included.

Table II-1 gives the erection percentages for process equipment, and Table II-2 gives erection percentages for "minor" equipment. From this last table it can be seen that erection costs are considerable!

If possible, costs for industrial buildings should be estimated separately. The total costs for several types of buildings are illustrated in Table III. These figures are average figures and must be used with caution. Also, for estimating building costs with confidence experience of the costs of a variety of buildings is desirable.

Another difficulty arises in the costing of high temperature, high pressure modern plants etc. In these modern plants special alloys are employed; these materials are more expensive than normal steel. Some prices for alloys are given in Table IV which shows for example that inconel costs £1300 per ton—28 times more expensive than mild steel. But from Table V it is apparent that a heat exchanger of inconel, diameter 40 in., is 4.50 more expensive than a carbon steel heat exchanger. The explanation is that with alloys the ultimate tensile strength may be higher, so thinner wall-thicknesses can be used. This is because the greater ultimate strength of the alloy compared with that of steel allows smaller wall thicknesses and therefore offers a less weighty exchanger.

As Inconel is very expensive, it is economical to make the supports and flanges of mild steel. It is true that inconel is more expensive to weld etc., but not proportionately so. On the whole labour costs remain constant or increase slightly with the alloy, only the alloy steel prices increase steeply.

But the costing of an Inconel exchanger must take into account the facts that costs for foundations, steel structures and of erection are similar to those for carbon steel heat exchangers. However, a portion of the pipelines will either be constructed in an alloy, or is lined, therefore the pipework will be more expensive. For this reason we cannot use the multiplying factors shown above for special materials, but instead must resort to correlation factors as provided by the relative costs for heat exchangers in Table V and relative costs for centrifugal pumps in Table VI. These data have been gathered from purchasing orders and must be taken as average figures. In this connection it is to be regretted that there is so little co-operation between cost-engineering staffs from different companies. Many companies have other cost data and correlation factors, multiplying factors, conversion factors and costs relative to carbon steel.

Example: Required a short-cut estimate for the cost of a heat exchanger in Inconel with 2000 sq. ft of surface and employing a shell of 40 in. diameter, given that a similar exchanger in carbon steel costs £2000. From Table V for inconel the factor is 4.5 hence the approximate cost of the exchanger is 4.5 × £2000 = £9000.

With the aid of Table I the total installed costs of the Inconel and steel heat exchanger can now be determined.

Example:		*inconel*	*steel*	
fob cost of heat exchanger		£ 9,000	£ 2,000	= 100%
Additional materials				
pipelines	45%	4,050	900	
foundations, site work, paving ...	10%	200	200	
Painting, cleaning, fire proofiing ...	5%	100	100	
insulation ...	15%	300	300	
steel structures, temporary facilities ...	25%	500	500	
electrical and miscellaneous ...	5%	100	100	
Total price heat exchangers with ancillaries ...		14,250	4,100	
Total erection costs	85%	1,700	1,700	
Heat exchanger costs including erection		15,950		5,800
All indirect costs ...	80%	1,600	1,600	
		17,550	7,400	
Ratio $\frac{\text{total installed costs}}{\text{fob price heat exchangers}}$		1.95	3.7	

This example illustrates a simple method of preparing more realistic and more accurate costs-estimates for chemical plants; the method can be applied to all equipment to enable the costs of plants including erection to be completely estimated.

[1] Stogens, M., *Brit. Chem. Eng.*, 1960, **5**, 2, 99.

TABLE II-1—Percentages for Erection of Equipment, when Constructed in Standard Materials

Process equipment	Percentage
Distillation towers, field fabricated	75
Distillation towers, shop fabricated	30
Pressure vessels	10
Exchangers, evaporators	5
Pumps and drives	5
Compressors and drives	5
Drives, only	5
Blowers	5
Heaters, kilns, furnaces, boilers	20
Reactors	10
Instruments	25
Transport equipment	10
Laenders, filters, dryers	10
Mills, crushers, extruders, blenders, centrifuges, autoclaves	15
Other Machinery	10

TABLE II-2

Additional Materials	Percentage
Pipework including valves	100
Instrument piping	125
Steel structures	20
Industrial steel buildings	30
Insulation	150
Painting	500
Foundation	150
Fire proofing	500
Brick lining in vessels, etc.	25
Transformers	40
Switchgear, prefabricated	30
Electric lighting	110
Electric power	60
Electric power and lighting (average)	75
Buildings, concrete	100
Temporary facilities	30

TABLE III

Costs of Buildings	
Industrial buildings, average	£4 to £5 per sq. ft
Industrial buildings, 3-storeys	5/- to 6/- per cu. ft
Industrial buildings, small	8/- to 10/- " "
Chemical storage building	6/- to 7/- " "
Compressor building	7/- to 8/- " "
Large storage buildings, general purpose	3/- to 7/- " "
Workshops	5/- to 6/- " "
Laboratories	12/- to 15/- " "
Offices	9/- to 11/- " "
Store-houses	4/- to 5/- " "
Dwelling houses	£3 to £4 sq. ft
Reinforced concrete	100/- to 110/- per cu. yd
Mass concrete	90/- to 100/- " "

TABLE IV

Costs of plate materials	*per ton* £
Carbon steel	46
13 Chromium	325
18 Cr. 10 Ni.	415
18 Cr. 10 Ni 2 Mo	550
18 Cr. 10 Ni + Ti	460
26 Cr 21 Ni	675
67 Ni 30 Cu-monil	1000
13 Cr 80 Ni 2 Cu-inconel	1300
99 Ni-nickel	1400
55 Ni 15 Cr 19 Mo 5 W-Hastelloy C	2500

TABLE V

Relative Costs for different materials for heat exchangers

Material shell	*Material tubes*	*Shell diameter* 15"	25"	40"
steel	steel	1	1	1
aluminium	aluminium	1.2	1.25	1.30
18 Cr 10 Ni 2 Mo	18 Cr 10 Ni 2 Mo	2.5	3.5	7
5 Cr ½ Mo	5 Cr ½ Mo	2	2.1	2.2
steel	5 Cr ½ Mo	1.15	1.20	1.25
steel	18 Cr 10 Ni 2 Mo	2.30	2.40	2.50
inconel	inconel	2.70	3.70	4.50
monel	monel	2.50	3	3.50
steel	hastelloy	7	8	9
steel	monel	2.1	2.2	2.3
99 Ni	99 Ni	3	3.5	4
18 Cr 8 Ni + Ti	18 Cr 8 Ni + Ti	3	3.5	4
steel	admiralty	1.25	1.30	1.35

TABLE VI

Relative Costs for Centrifugal Pumps	
cast steel/cast iron	1.00
18 Cr 8 Ni	2.00
18 Cr 10 Ni 2 Mo	2.50
18 Cr 8 Ni + 1 Ti	2.50
5 Cr ½ Mo	1.60
12 Cr	1.75
Monel	2.75
Inconel	3.25
nickel 99%	5.00
Hastelloy	8.00

658.061.3

MANAGEMENT IN THE NEXT DECADE

A brief survey of seven of the numerous papers presented at the Twelfth International Congress of Scientific Management

by J. STRAUSS, B.A.

THE recent International Congress of Scientific Management (abbreviated to C.I.O.S. XII) was the twelfth in a series of triennial gatherings of delegates from member nations of C.I.O.S. (Comité International de l'Organisation Scientifique). This was the first time that the meeting had been held in Australia, and of more than 2000 delegates who registered for the sessions held in Sydney (February 22 to 29) and Melbourne (February 29 to March 4), over 250 had come from overseas.

The general themes given for the Congress were "Management's Methods in the Next Decade" and "Management in a Developing Country", the latter being the title of the address with which the Prime Minister of Australia, the Rt. Hon. R. G. Menzies, opened the Melbourne section of the Congress. A brief review is presented here of some of the papers which should be of interest to chemical engineers in management.

Productivity Improvement

*(a) Management Methods in the Next Decade: Improving Established Methods, by R. Caussin**

M. Caussin, after a brief résumé of the history of management in the early years of this century, reviews the techniques employed today, viz.: time and motion study; the planning, preparation and procurement of work; costing and budgeting; and quality controls. From this review, he predicts that, in so far as established management techniques are concerned, the main development will lie in the extension of research (especially in the preparatory stages) and in a more scientific approach to the development of new technical processes and methods of work, but that a new factor of even greater importance will be the recognition of the necessity for a synthesis of the human sciences (psychology, physiology and sociology) with the technical and economic sciences to bring about greater co-operation between research workers and those who apply their findings, and that management will become increasingly concerned with this general interaction of factors rather than with specific problems in isolation.

(b) Methods and Techniques to Improve Productivity: Developing Newer Methods, by A. K. Watson†

The main concern of this paper, apart from general predictions of increased emphasis on the work of administration and management, and of increased awareness by industry of its social responsibilities, is with the importance for management of what the author terms "the technology of information".

He feels that, in making decisions for long-range planning, the so-called "sound business judgment" of executives will be replaced by "systematic risk-taking" based upon an analysis of the variables of any situation. Such analysis can only be effective if supplied with adequate information as to these variables, but once a sufficient quantitative supply of information is obtained, the automatic computer becomes the tool necessary to process and develop it, and the paper closes with a number of specific suggestions as to the possible applications of such computers.

Co-operation in Commerce and Industry

*Wages Policy in the Netherlands, by Dr. J. W. de Pous**

The fact that Holland has probably the lowest loss of working time from strikes of any country in the world (less than $\frac{1}{4}$ of that in the U.K.) can be largely attributed to the wages policy followed by the government, industry and the labour unions in joint consultation. The government, representing the interests of the country as a whole, attempts to keep economic stability paramount in the decisions arrived at by collective bargaining between industry and the unions. Wage differentials, based on margins of skill (approximately 10% for semi-skilled, 20% for skilled workers) and margins for geographical location of work (urban or country) as well as occupational differentials, are also considered in these discussions. On the basis of the actual experience of the Netherlands, the author expresses the belief that by some measure of government control a policy of full employment need not lead to inflation, the average wage level need not rise faster than the level of productivity, and, further, that a long-term equilibrium between the supply and demand of available labour could be achieved through such policies.

Long-range Business Planning

The Influence of Fixed and Variable Factors, both National and International, by Prof. M. Marconi†

Long-term production planning on an economic basis is discussed in considerable detail. The major contentions on which this discussion is based are that the last decade has been characterised by a general increase in industrial (and to some extent agricultural) productivity, a growth in the volume of international trade, and a marked decline

* Managing director of the Comité National Belge de l'Organisation.
† Vice-president of I.B.M and President of I.B.M. World Trade Corp.

* Minister for Economic Affairs, Netherlands Government.
† Of the International Chamber of Commerce and of the Comité Européen pour le Progrès Economique et Social.

in the fluctuations of demand, brought about by the economic policies of post-war governments. The introduction of large trade blocs, such as the European Common Market, may also help in this reduction of uncertainties, but at the same time introduces a new complexity into the business problems of individual members, thus posing new problems of forecasting while making the need for their solution increasingly important.

For any particular firm, it is necessary to predict not only the extent of the future market, but also the share which the company can hope to have in it. If the company dominates the supply to the market, it will be able to dictate the price of the commodity. This is obviously easier for a large firm, which, moreover, takes much less risk when introducing a new product than does the smaller firm with its limited production.

The difficulty of prediction is increased by the interaction of individual factors such as national income, technical progress, supply and demand. Although developments in government economic planning and in international co-operation make a mathematical economic approach to long-term planning more feasible, Professor Marconi suggests the human intuition of the entrepreneur is still the final element to be used in the making of decisions.

Management of Research

(*a*) *Management of Research, by Sir George Nelson** (*Lord Nelson of Stafford*)

The author is concerned with the type of decisions which management (whether industrial or national) must make in directing research, and with the factors which must be considered in making these decisions. The primary decision determines the amount of research to be done, and whether the emphasis is to be placed on basic research, applied research or product development. A major factor in reaching this decision is the size of the company. On the basis of 1-2% of the national production spent on research, a company must have a turnover of at least half a million pounds before it can finance adequately even a small research laboratory. A turnover ten times this amount is required to finance a £0.1 million per annum research organisation. Therefore, the author suggests that it may be more worthwhile for a company which could only run a very small laboratory to employ graduate staff to study the technical literature and maintain close contact with research workers in their field in research associations and universities.

Other sections of the paper deal with the staffing of industrial research laboratories; the responsibilities and activities of the different types of research and development scientists and of management; and the organisation and financing of the laboratories.

(*b*) *The Growing Edge of Innovation, by J. R. Killian**

The author emphasises the accelerating pace of change, which is being brought about by an exponential growth of scientific knowledge and a compression of the time lag between discovery and its commercialisation He argues that it has become a major responsibility of management to pursue a policy of innovation in order to improve a company's products. This involves more attention both to basic research and to its supporting research, analytical engineering, in which the available knowledge is scrutinised to determine the feasibility of new ideas. It also involves proper recognition of the work of scientists and engineers as such, rather than as managers, and an effective use of the limited supply of creative scientific talent available. To enhance creative efficiency, the scientist must have freedom of publication; of selection of problems, and of their abandonment; and of application of the work to demonstrate its merits. Moreover, too many helpers can handicap gifted men: experience has shown that great advances are more likely to come through the creative ideas of individuals than through the massive attacks of "crash programmes".

The complete proceedings can be obtained in the United Kingdom from The British Institute of Management, 80 Fetter Lane, London, E.C.4.

* Chairman of English Electric Co. Ltd.

* Chairman of Massachusetts Institute of Technology and lately scientific adviser to the President of the United States of America.

Conference on North American Chemical Industry

A CONFERENCE sponsored jointly by the Chemical Economics Division of the Chemical Institute of Canada and the Commercial Chemical Development Association of the U.S.A. will be held in Montreal on October 18. This one-day conference, entitled *The Chemical Industry—Canada and the U.S.A.*, will be attended by about 300 representatives of both countries, who will study the problems facing the industry in North America.

The format of the programme has been designed to provide a frank and searching analysis into such topical and important problems as return on investment, trade, finance and research, together with ample opportunity for discussion.

A half-day will be devoted to each country. The morning session, dealing with the Canadian chemical industry, will feature two Canadian speakers, W. N. HALL, president of Dominion Tar & Chemical Co. Ltd., and F. P. WILSON, executive vice-president, Union Carbide Canada Ltd. Moderator will be L. P. MOORE, president of Cyanamid of Canada Ltd. In addition, two inquisitors representing the U.S. chemical industry will be charged with leading the question period following the formal presentations of the speakers.

The afternoon session will deal with the chemical industry in the U.S.A. and a panel of U.S. speakers selected by the C.C.D.A. will discuss its problems. Two Canadian inquisitors will lead the question period for this part of the programme.

The C.C.D.A., founded in 1947, has a membership of nearly 500 representing 150 companies in the chemical and allied products industries in the United States. The purpose of the organisation is similar to that of the Chemical Economics Division of the C.I.C. and a joint meeting of the two groups to discuss problems common to the chemical industries in the two countries has been under discussion for some time. The October joint conference will also be the fourth national meeting of the Chemical Economics Division, and will be its most ambitious undertaking.

Errata

Entropy — A Thermodynamic Concept and its Application, p. 702 (October)

In the first sentence of the penultimate paragraph delete (Stage IV in Fig. 5) and insert ("used in the Heylandt plant)".

Radioactive Tracing of Phenol Losses in Oil Refining, p. 710 (October)

The diagram for Fig. 1 is shown as Fig. 2 and vice versa.

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AMERICAN LETTER

Engineering Manpower

WITH the exception of the apparently limitless demand for electronic engineers, it is now some four years since a peak was reached in a general shortage of engineering manpower. Undoubtedly, the situation was aggravated by numerous professional recruiters and personnel managers who toured North America, visiting universities, conventions and large industrial areas in order to stockpile both new graduates and experienced men. During the 1958 recession there were many instances of these swollen staffs being drastically pruned—particularly in some chemical engineering and construction organisations—to an extent unthinkable in Britain.

Another Future Shortage?

An invaluable barometer of the U.S. engineering personnel climate is provided by the annual report of the Engineering Manpower Commission of the Engineers Joint Council, which undertakes yearly surveys of trends in the demand for engineering graduates in industry and government.

The E.M.C. survey undertaken during the third quarter of 1959 revealed some important short-term and long-term trends. Of immediate interest was the news that the net increase in the number of engineers employed by industry in 1959 was more than double the increase in 1958 and would have been greater had a sufficient, suitable supply been available. Fortunately, a greatly increased number of college men in 1959 (38,162 B.S. graduates alone) prevented a large numerical shortage, but in many cases the need for experienced men remained unfulfilled.

The 1959 E.M.C. Report drew attention to some important factors concerning the supply of engineering manpower. For example, a current shortage has been partly avoided by a substantial reduction in the number of graduates being conscripted for active military service and also by an increase in the number returning from inductions of previous years. Nevertheless, the future situation looks somewhat serious, since, for two consecutive years (1958 and 1959) enrolments in engineering colleges have declined. Hence, unless increased numbers of students can promptly be attracted to engineering, by assurances of stability and recognition as well as high initial pay, the opposing factors of an increased demand and a reduced number of graduates are likely to lead to another acute shortage of men in the mid-1960s.

As regards chemical engineers, some indication of the relative demand might be inferred from comparisons of 1959 starting salaries. The median monthly starting figures for all engineers were $510, $600 and $825 for B.S., M.S. and Ph.D. graduates. Corresponding figures for chemical engineers were below these median levels, being $500, $563 and $745 respectively. Petroleum engineers fared much worse, the respective monthly figures being only $480, $531 and $675. These average commencing salaries compare unfavourably with those offered in other fields; for example, the monthly figures for B.S. entrants to the aircraft industry were about $526, while Ph.D.s in the machinery business averaged an initial $868. Nevertheless, even the lower salary levels are sufficiently attractive to numbers of foreign graduates and the predicted engineering manpower shortage may give rise to an increase in the employment of both newly graduated and experienced men from Europe.

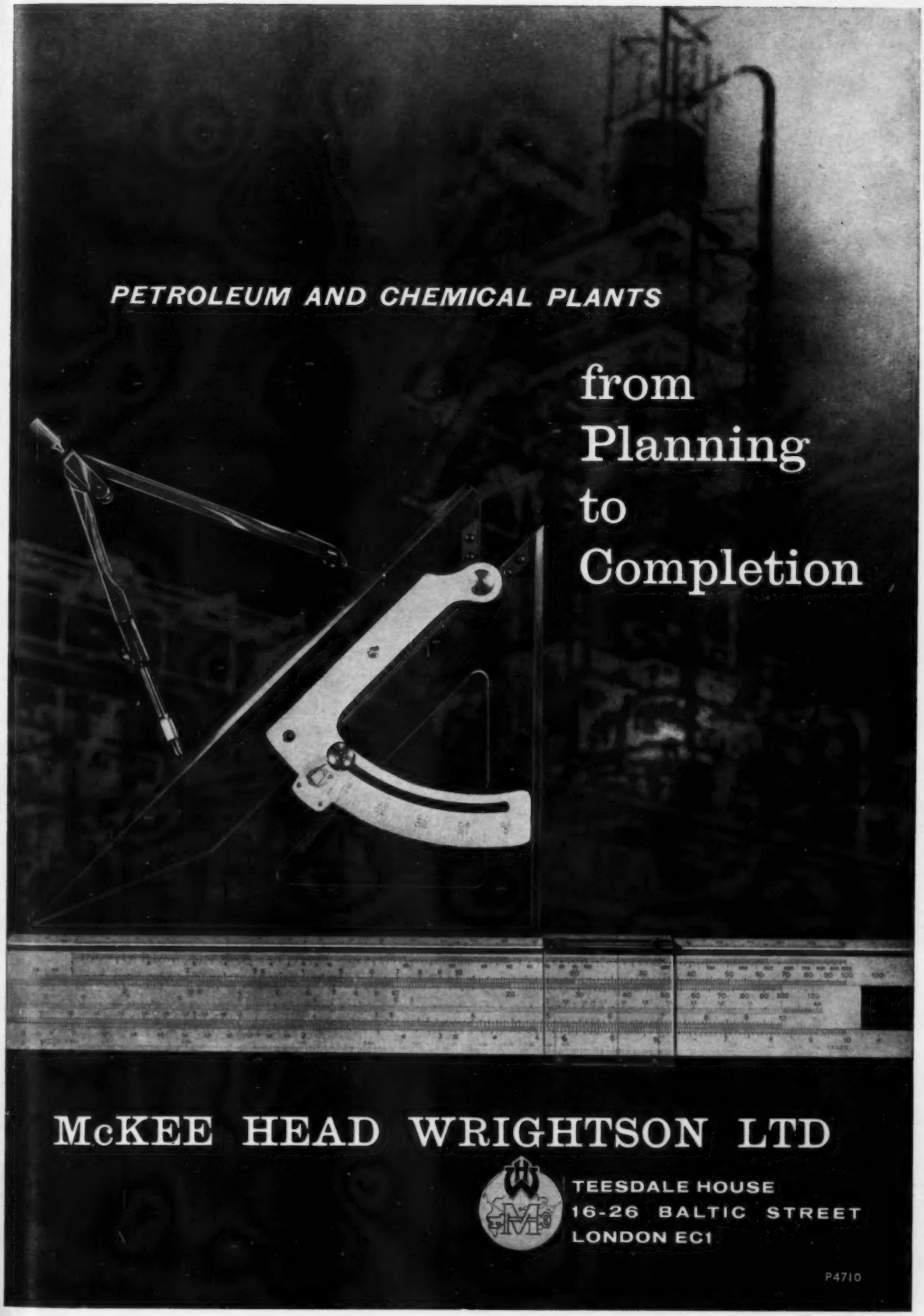
The demand for engineering technicians is also growing, according to the last E.M.C. survey. At the present time, a 10% increase in numbers is sought, in addition to about 10% currently undergoing in-plant upgrading. The survey also showed that the ratio of technicians to graduate engineers for all industries averaged 0.5, while the figure for Government engineering occupations was 1.2. The ratio for the chemical industry was only 0.2, which suggests that a future dearth of chemical engineers might be partly offset by hiring and training more technicians. This would appear to be a logical policy, since qualified and experienced men could then be employed to better advantage.

Despite a high level of competence and dedication, numerous U.S. engineers are deeply concerned about their professional and social status relative to other specialists.

This current preoccupation with status is generating a good deal of confusion, both in the minds of the public and the engineers themselves. For instance, there is a loud clamour in some quarters that, in addition to a university degree—preferably a Master's—plus membership in one or more recognised engineering or chemical societies, each engineer must also have a State licence before being legally entitled to call himself a professional man. Since these licences are granted by each individual State, the situation could rapidly get out of hand; already, itinerant engineers in construction work have to acquire an art gallery of separate licences (often gained by examinations where reciprocity does not exist) in order to earn a legal living.

Although the examining and licensing of civil and municipal engineers is laudable in the interests of public safety, many engineers employed in private industry have been stampeded both by their employers and their own brethren into obtaining additional qualifications in the form of a State licence, only to find that salary levels remain the same and the public is as unimpressed as before. This dilemma has not only led to a spate of society meetings, articles and committees designed to rationalise the status of engineers, but it has created an opportunity for the trade unions to offer their own panacea for higher remuneration and better recognition. In simple terms, they regard a professional man as one who "hangs out his shingle" and view engineers employed *en masse* by large corporations as merely rank-and-file employees who, accordingly, have much to gain by union organisation.

A well-known recruitment firm, Executive Manpower Corporation, recently published the results of a survey covering 145 firms in 29 industries, which showed that the major manpower need, amounting to 27% of the total, was for top-level sales executives. This was followed by a demand for engineering managers (23%) and production specialists (19%). In the 15 chemical companies contacted, average requirements for top-level men were 3.3 per company, compared to an industry average of 2.5 men. Moreover, the chemical industry was the only one indicating an above-average need. It is also interesting to note that the chemical industry showed one-third more $15,000 to $20,000-a-year jobs available than industry as a whole, and correspondingly less in the $10,000 to $15,000-a-year bracket. A present-day engineering or science student seeking enlightenment might well conclude that an ability to sell distillation columns or detergents is much more likely to help him reach the coveted $50,000 a year goal than all the advanced degrees, professional licences and union support now advocated.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PROCESS ENGINEER'S NOTEBOOK

Electrode Level Indicators

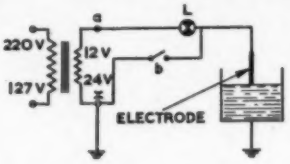


Fig. 1. Automatic level indicator. a, x—terminals of secondary winding of transformers, L—signal lamp; b—switch.

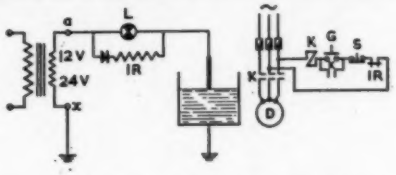


Fig. 2. Device for starting and stopping transfer pump. IR—intermediate relay; D—motor; K—contact and coil of starter; S, G—"stop" and "go" knobs.

RADIOACTIVE AND PNEUMATIC level indicators are widely used for indicating the levels of corrosive liquids. The former are somewhat expensive and the others have the disadvantage of requiring a compressed air supply, non-corrosive compressed air lines near the tank containing the liquid and the carry-over of traces of corrosive from the discharged air.

It has been reported that a Russian chemical factory* has developed a simple and inexpensive method of remote level indication which avoids some of the disadvantages of the above two methods. The method employed depends upon the liquid electrical conductivity. The device consists of a rod of stainless steel which is inserted in the tank through an insulated plug of pvc. To the rod (an electrode from an arc welder) is attached a cable from the secondary winding of a single-phase transformer with a voltage of 220/12 volts (24 volts) or 127/12 volts (24 volts). The other end of the secondary winding of the transformer and the body of the tank are earthed. At the maximum level of the liquid the circuit of the secondary winding of the transformer is closed and the current will pass through the circuit; the signal lamp (L) then lights up, indicating that the tank under control is full. The switch (B) serves to test whether the lamp is in working order.

This device has been used for the measurement of levels of the individual tanks in a tank farm.

In this case, to the terminal (a) of the secondary winding are attached electrodes corresponding to the number of tanks. If it is required to signal several levels of liquid in a tank, then electrodes are attached to the walls of a tank corresponding to the number of measurements desired.

In order to stop the transfer pump when the maximum level has been reached, the current to the driving pump is interrupted by means of the device shown in Fig. 2. In this the lamp is in parallel with the coil of the relay (I.R.) This simple device is evidently promised wide application in the partial automisation of Russian chemical plants.

* D'yadkov, V. I. *Khim. Prom.*, 1960, **3**, p. 85.

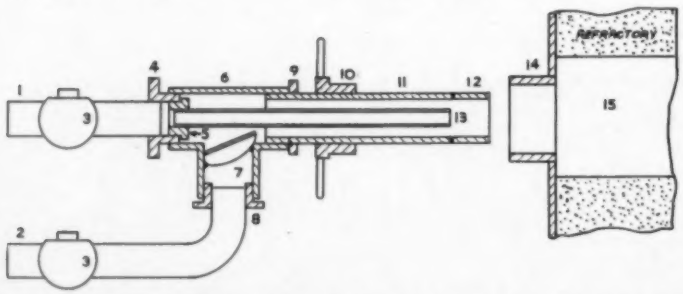
A Towns Gas Burner

ALTHOUGH THERE ARE burners commercially available for practically every possible method of burning towns gas, there are still occasions when a simple "knock-up" burner is required. The burner described here was made entirely from screwed pipe fittings. The simple construction of the pipes and fittings is illustrated in the drawing. A length of 1½ in. B.S.P. pipe (optionally tipped with stainless steel) was screwed into a 1½-in. B.S.P. tee. Air was supplied through an axially-placed ¼-in. B.S.P. pipe. Towns gas was supplied through the side of the tee and was given a tangential swirl by the baffle. The overall length of the burner was made to suit the application, but a critical clearance length between the end of the central air pipe and the end of the outer tube of 2¼ in. (i.e., 1½ × burner tube diameter) must be maintained for flame stability.

The burner has a remarkably high output, and stable flames have been obtained when burning 928 scf/h of towns gas with an air : gas ratio of 5 : 1. Flame stability at these high consumption rates is brought about by imparting a tangential swirl to the gas and confining the air supply to a high-velocity jet in the centre of the burner pipe. In this way "blow-off" conditions are avoided at the mouth of the burner pipe. At lower gas rates (about 600 scf/h) air : gas ratios of 8 : 1 and above have been obtained. This is of particular interest when a hot reactive flue gas is required, as, for example, in burning-off operations. In tests checking the dimensions of the flame it was found that at the maximum consumption rate, i.e., 928 scf/h with a 5 : 1 air : gas ratio, the flame could be confined in a 4-in.-diameter combustion tunnel to a length of 16 in.

The burner has been scaled down to a 1-in. B.S.P. outer pipe and a ¼-in. B.S.P. air pipe. Stable flames have been obtained using up to 240 scf/h of gas at a 4 : 1 air : gas ratio.

W. H. NEWTON, G. O. DAVIES



1—1-in. B.S.P. air supply at 10 psi; 2—1-in. B.S.P. gas supply at 10 psi; 3—non-return valves; 4—1¼-1-in. B.S.P. reducing bush; 5—1-½-in. B.S.P. reducing bush; 6—1¼-in. B.S.P. equal T-piece; 7—tangential directing baffle; 8—1¼-1-in. B.S.P. reducing bush; 9—1¼-in. B.S.P. lock nut; 10—2-1¼-in. B.S.P. reducing bush with two ¼-in. dia. handles welded on; 11—1¼-in. B.S.P. burner tube, externally threaded to carry 10; 12—1¼-in. I.D. stainless-steel tube; 13—¼-in. B.S.P. air supply pipe; 14—2-in. B.S.P. socket to support burner; 15—combustion chamber.

Control Valve for Low Rates of Flow

SOME SMALL-SCALE chemical processes require gas flows of the order of 1-3 m³/hr. In a number of such cases it is also necessary to shut off completely the flow of gas.

A modification to a 6-mm pneumatic-motor valve with a minimum throughput of 10-15 m³/hr (3-5% of the maximum throughput) to give the above flow rates has been described in a recent Russian publication* (Fig. 1).

The following were the alterations made to this valve:

(1) The needle of the valve rod is given the form of a cone (instead of the double bevel), thereby decreasing the diameter of the upper part.

(2) The seating is made removable, with a seal of ptfe (Fluoroplast-4); this makes is possible for the needle to seat more closely and thus cut off the gas flow completely if required. By the choice of rods and removable seatings, it is possible to change the magnitude of the gas flow, changing over the rods and seating taking not more than 30-40 min. (Fig. 2a). In the case of highly corrosive media, to avoid the needle wedging in the seating, the latter is pressed in the form of a bush into the body of the valve and then drilled (Fig. 2b).

(3) In the existing design the gasket has a stuffing box with a gland nut which is screwed inside the packing housing. A further modification to the design makes use of a deeper stuffing box with the packing tightening carried out by a hollow nut fitted over the gland chaser (Fig. 2b). This measure allows the packing to be rapidly replaced, whereas in the present model in order to do this the gasket housing has to be stripped right down to the notch on the stern.

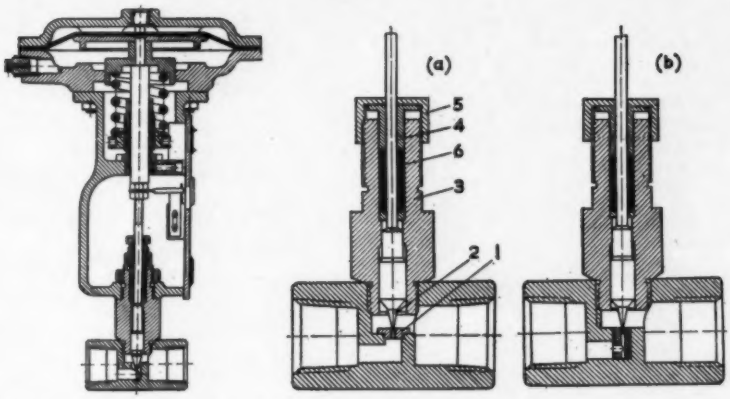
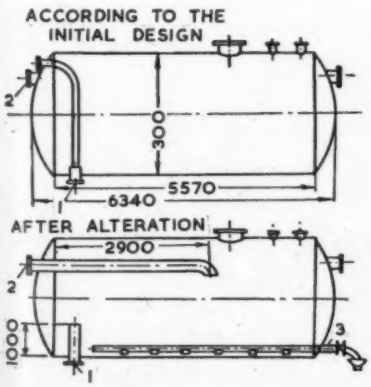


Fig. 1. Pneumatic control valve before modification. Fig. 2. Lower part of modified control valve. 1—removable seating; 2—altered needle; 3—lengthened gasket housing; 5—gland nut; 6—packing.

* Strunkin, M. G., and Gaevoi, V. I. *Khimicheskaya Promyshlennost'*, 1960, **3**, 84-85.

Wash Oil Collector Redesign

BENZOLE SCRUBBERS AT a Russian coking plant, which were equipped with spiral metallic packings, gave trouble through an accumulation of solid impurities upon the packings. Pressure drop, which initially was 1.5 to 2.0 mm water gauge per metre height of packing, occasionally approached a figure ten times greater than this. A contributory factor to the high pressure drop was the presence of water and emulsion in the oil used as wash liquor in the scrubber. This was due to the faulty design of the collector for debenzolised oil which proved ineffective for separating emulsion and water from the wash oil.



The original design of the collector, which is shown in the upper half of the diagram, was therefore modified. First the oil intake pipe (1) was raised by 800 mm, whereas previously it was 200 mm above the bottom of the vessel. This alteration enabled the water and emulsion to settle and accumulate in the non-working zone of the collector. The overflow connection (2) was extended into the collector by 3000 mm.

Drain pipe (3), 89 mm in diameter and with an external outlet, runs along the bottom of the collector from end to end. Six open branch pipes, each 50 mm in length, were welded on to the pipe at equal distances apart; the branch pipe holes are arranged at a distance of 20-30 mm from the bottom of the collector. The drain pipe terminated outside the collector in a connection with a steel wedge slide valve and an outlet, passing into a funnel; the pipe extended from the funnel to a sludge collector. Thanks to the design of this drain pipe, it was possible to drain the settled water and emulsion simultaneously from six points along the cold oil collector.

These alterations eliminated the trouble at the towers arising from faulty separation of emulsion and water from the cold debenzolised oil.

Abstracted from *Coke and Chemistry* (U.S.S.R.), 1960, 5, 40-42.

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

Book Reviews

Fine Particle Measurement
by Clyde Orr and J. M. Dallavalle
Macmillan, New York, 1959, 354 pp., 73s.6d.

THERE is a famous German nursery song with which many a child is familiar:

"Knowest thou how many stars stand
in heaven's firmament?
Knowest thou how many pebbles on
the shores the world all round?
God, the Lord, He counted all, not
one He missed in all His care."

Today it is becoming relatively easy to "count" particles, but to "size" them adequately is a much more stimulating and rewarding exercise with which this book is concerned.

The late Professor J. M. DALLAVALLE is renowned for his research work in particle mechanics and his book, "Micromeritics" (the technology of fine particles), which was first printed in 1943, was enlarged and revised in 1947. The volume under review which he published with his senior colleague and now successor at Atlanta, Georgia, deals entirely with the technique of measurement of size, surface, weight and pore volume of fine particles, and with the analysis of the data. More than seventy techniques are described, ranging from microscopy to radiation scattering for size measurements, from permeametry to sorption methods for surface and pore evaluations.

It is a book which will be found in research laboratories in the fields of chemical engineering, physics, mineral dressing, etc., and although it is comprehensive in scope, it does not do more than survey the field, giving the basic principles of each method and their limitations. It will be found inadequate in practice for know-how on the construction and use of apparatus, but the authors have added 400 references to the text in an endeavour to close the gap. It is thus in its present form valuable for comparative studies of methods of fine particle measurement, but one ventures to hope that it will follow the path of "Micromeritics" and be enlarged within five years into a major encyclopædic volume on the subject which is badly needed.

P.E.

Radioactive Wastes—Their Treatment and Disposal
Edited by J. C. Collins.
E. & F. N. Spon Ltd., London, 1960, 239 pp., 55s.

WITH the increasing use of radioactive materials in industry, research institutions and hospitals, the amounts of radioactive waste which arise and which have to be disposed of in a safe way are constantly increasing. It is therefore most useful to have compiled in a single booklet the essential aspects of this problem: the sources of radioactive waste, the hazards and measurements of radioactivity, and the methods of treatment and disposal of liquid, solid or gaseous waste.

The book has been written in the manner of a symposium by eight authors, all of whom are or have been closely connected with the problems discussed. It thus represents a fairly comprehensive and up-to-date picture. The only exception is the very short article on the law of radioactive wastes in Great Britain, which has been invalidated by the newly passed "Radioactive Substances Act, 1960" (8 and 9 Eliz. 2. CH 34). This, however, should not detract from the overall value of the book. This provides not only technical data for chemists and engineers, but also much-needed and easily digestible background information for factory inspectors and executives and for all those who, from necessity or from interest, wish to know how the world deals with these new and potentially dangerous materials which will be the mark of the next centuries.

E. GLUECKAUF

Economic Control of Interconnected Systems
by L. K. Kirchmayer
Chapman & Hall, London, 1959, 208 pp. 100s.

THE subject of this volume is master overall control in one particular industry—that of electricity generation and supply. The dynamic characteristics involved in steam or hydro-electric generating stations are more or less known. The problem, then, is the most economic integration of supply and distribution to fulfil fluctuating demand in given connected areas. The different aspects of this problem are considered and it is shown how the whole problem is amenable to solution with analogue computation.

The book is not easy for the non-electrical engineer to follow even if he can understand the mathematical treatment, but it is stimulating in showing what can be achieved in a real, many-component, dynamic control problem. Unfortunately, the units of the chemical industry are often dynamically far more complex, involving competitive chemical reactions. This is not so readily soluble as the purely physical system. The overall economic refinery control system is still far distant.

J. S. M. BOTTERILL

Mechanical Design of Laboratory Apparatus
by H. J. J. Braddick
The Institute of Physics, Monograph for Students, 1960, 46 pp., 6s.

THIS monograph, intended for students in courses for Higher National Certificate in Applied Physics and in the first two years of a degree course, deals with the design of instruments and assemblies for laboratory use. It is the contention of the author that it is sometimes more economical to "do it yourself" than to buy it "ready-made". He also feels that the knowledge of the principles of design would enable the prospective purchaser to select the best tool for the job.

The main chapter deals with the principles of mechanical design from a functional point of view and is concerned with kinematic considerations: location, sliding motion, translational and rotational connections, appreciation of kinematic design, bearings, spring constraints, motional hysteresis, the idea of sub-assemblies, etc.

In the short final chapter the author deals with the embodiment of the above principles: advantages of castings and fabrication by machining from solid bars, plates or sheets.

This monograph should prove useful by giving to the young student a background for judicious selection of instruments from commercial sources and to the mechanical enthusiast some of the "do-it-yourself" know-how.

M.P.

Major Activities in the Atomic Energy Progams, January-December 1959, U.S. Atomic Energy Commission, 1960. $2.

THIS IS THE Commission's Annual Report to Congress for 1959. It consists of three parts and an appendix. The parts are: One, The Atomic Energy Industry in 1959 and Related Activities; Two, Major Activities in Atomic Energy Programmes; Three, Management of Radioactive Wastes. Under the last heading the report gives attention to sources and problems, waste management, research on waste disposal, environmental research and finally licensing, regulation and inspection.

Indian Institute of Science Golden Jubilee Research, Volume 1909-1959, Bangalore, India, 1959

THE INDIAN INSTITUTE of Science came into existence in 1909 with the main objective of providing for advanced instruction and conduct of original investigations in all those branches of knowledge likely to promote the material and industrial welfare of India. As one of the special features of jubilee activities, this Research Volume has been brought out to commemorate the occasion.

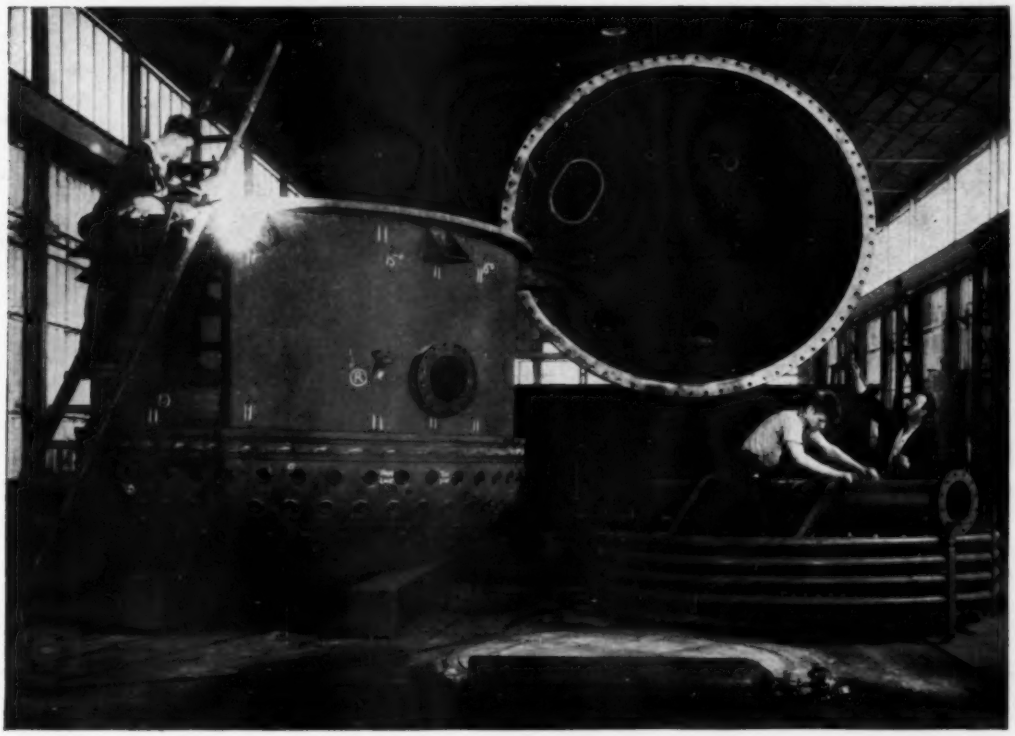
Among the papers are some reporting work in pure and applied chemistry and in heat transfer.

Lehrbriefe für Kältetechnik, Nos. 16, 17, 18, 1959: 19/20, 1960 Verlag C.F. Müller Karlsruhe. Each Lehrbrief DM 1.30. Binders for sets DM 1.20.

THIS EXCELLENT SERIES continues now with notes only on electrical technology and refrigeration proper. It may be recalled that earlier sections have dealt with pure physics and technical calculations. In electrical technology, the industrious mechanic following the series has now been led up to a discussion of switchgear, safety devices and relays. In respect of refrigeration, he will have calculated power requirements for compressors and cooling surface area for liquefiers.

Choice of Careers, No. 94 Laboratory Technicians and Assistants, 2s. 6d. No. 100, The Scientist, 1s. 3d. H.M.S.O.

THIS SERIES now reaches its century. The hundredth pamphlet gives most attention to the basic sciences. Further reviews projected include "Mathematics" and "Applied Science and Technology".



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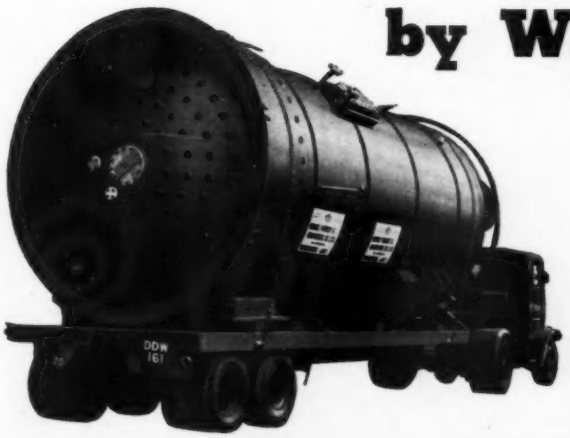

Two recent contracts carried out for Monsanto Chemicals Ltd., illustrate a selection from the comprehensive range of fabricated constructions produced for industry.

Above: Work in progress on the construction of two mild steel carburettors.

Left: One of two mild steel carburettors.

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W 52

NOMOGRAM SHOWING VAPOUR VELOCITY IN BUBBLE PLATE TOWERS

by D. S. DAVIS

Head, Department of Pulp and Paper Technology, University of Alabama

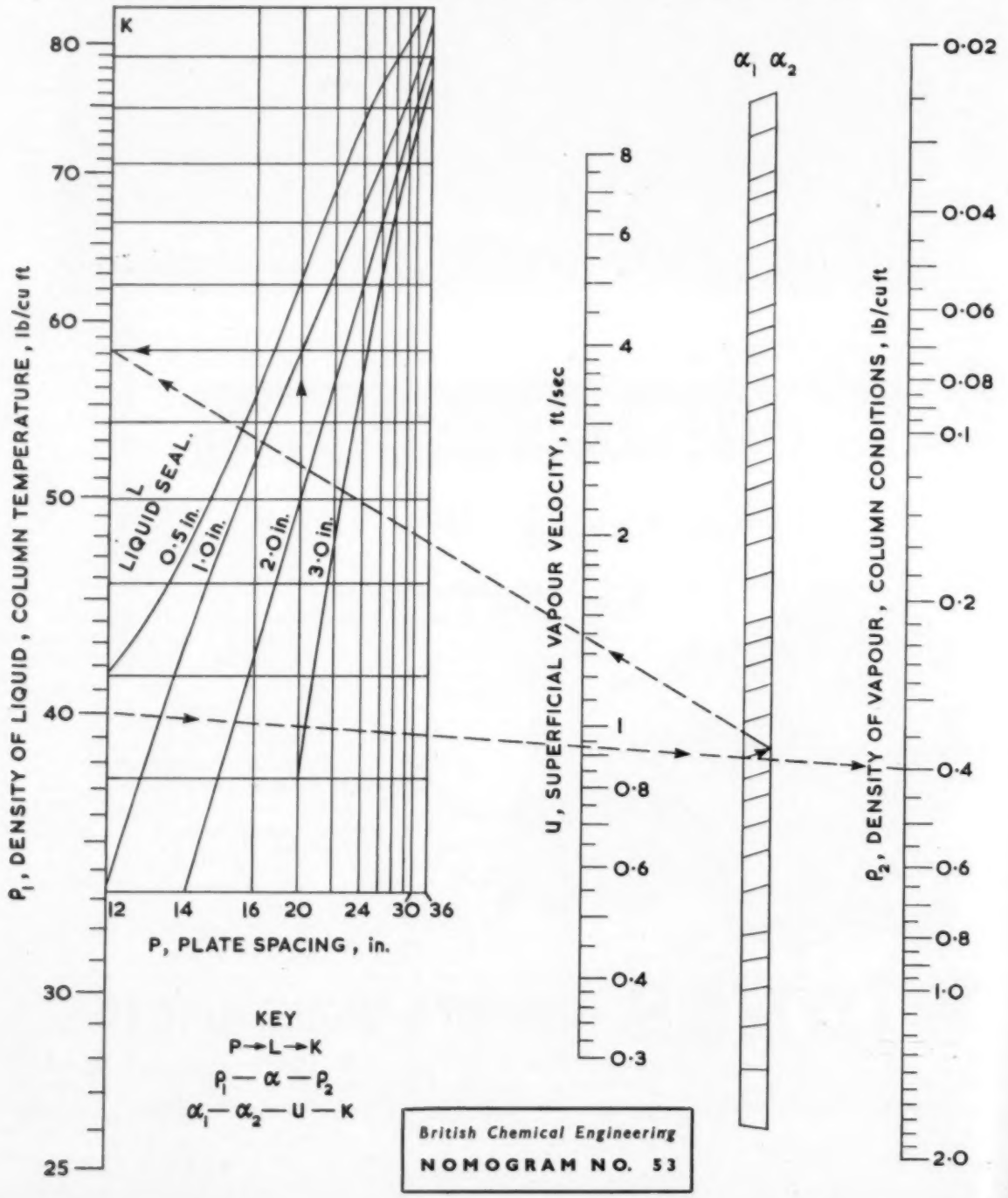
The superficial vapour velocity in bubble plate towers can be calculated by means of the equation[1]

$$u = K\sqrt{\rho_1/\rho_2 - 1}$$

where u = vapour velocity, ft/sec, based on total cross-sectional area of column;
ρ_1 = density of liquid at column temperature, lb/cu ft,
ρ_2 = density of vapour at column conditions, lb/cu ft.
and K depends upon plate spacing and depth of liquid seal.

The accompanying nomograph, constructed through application of methods described previously,[2] enables rapid and accurate solution of the equation. The use of the chart is illustrated as follows: What is the superficial vapour velocity in a bubblecap plate tower when the densities of liquid and vapour at column conditions are 40 and 0.4 lb/cu ft respectively, the plates are spaced 20 in. apart and the depth of the liquid seal is 1 in.? In accordance with the key, follow $P = 20$ to the curve for a 1-in. liquid seal and proceed to the K-scale at the left. Then connect 40 on the ρ_1-scale and 0.4 on the ρ_2-scale with a straight line and note the intersection with the α_1-axis. Follow the guide lines to the α_2- axis and connect this point and the point on the K-axis with a straight line, which crosses the u-scale at the desired velocity, 1.39 ft/sec.

REFERENCES
[1] PERRY, J. H., "Chemical Engineers' Handbook", 3rd ed., p. 597, McGraw-Hill Book Co. Inc., New York, 1950.
[2] DAVIS, D. S., "Nomography and Empirical Equations", Chapter 6, Reinhold Publishing Corporation, New York, 1955.



BCE 8565 for further information

CHEMICO BUILDS NITRIC ACID PLANT IN SIX MONTHS

It took just six months for Chemico to successfully complete a 120 ton per day nitric acid plant in Lawrence, Kansas. Until the client gave his final "go-ahead," not an hour of drafting or engineering had been done on the project—not a single piece of equipment had been placed on order. Yet, six months from that date, the plant finished its acceptance test run, producing at above rated capacity.

With 34 nitric acid plants in operation all over the world, and three more in the design stages at this very time, Chemico maintains its position of leadership in this field. In building plants to produce Ammonia, Urea, Nitric Acid, Acetylene, Methanol, Hydrogen, Sulfuric Acid and other chemical and petrochemical products, Chemico is setting new standards for the entire engineering industry.

This six month performance for a nitric acid plant follows closely the recent successful completion of an ammonia plant in ten months. It is not just the time factor alone which sets Chemico plants apart, however. Chemico clients know that they are buying efficient, economical, proven processes which assure ease of start-up and simple, safe operation. If you are considering building a new plant or enlarging present process facilities, let Chemico help you get the most for the capital you invest. Write for the General Bulletin which describes the wide range of Chemico's activities.

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RECENT CHEMICAL ENGINEERING THESES FOR HIGHER DEGREES*

Heat Transfer to a Film of Water Flowing over a Heated Vertical Surface

by Vincent McIntyre (Ph.D., Manchester University)

An investigation has been carried out into the behaviour of a liquid film flowing down the inner surface of a vertical tube surrounded by a heating annulus. Particular attention was paid to the factors influencing the minimum liquid flow rate required to maintain a continuous film on the heated surface.

The main factors influencing the minimum wetting rate were found to be the temperatures of the heating annulus, the temperature of the inlet film and the nature of the surface over which the film flowed.

The minimum wetting rate could be represented by an equation of the type

$$\Gamma_m = A\, T_{ann}{}^a\, T_f{}^b$$

where Γ_m was the minimum wetting rate in lb/ft hr; T_{ann} and T_f were the heating annulus and film temperatures respectively and A, a, b were constants whose value depended on the surface examined.

When the difference in temperature between the inlet film and heating annulus was less than 15°C, the minimum wetting rate was independent of the heating annulus temperature and remained almost constant for any given film temperature. When the difference was greater than 15°C, the minimum wetting rate was greatly affected by the value of the heating annulus temperature, and the values of the minimum wetting rate were higher than those found when the temperature difference was less than 15°C by as much as a factor of 30.

The cause of film breakdown was assumed to be surface tension differences on the film surface. Film breakdown resulted in a sharp fall in the value of the film heat transfer coefficient.

Experiments were conducted on smooth and rough copper tubes and on chromium-plated tubes.

The Corrosion of Mild Steel by Sulphur Dioxide

by A. J. MacNab (Ph.D., Manchester University)

The corrosion of certain sections of carbon black plant is described, focusing attention on the early attack experienced at low temperatures, which is shown to be due to sulphur compounds in the absence of oxygen and above the dew-point. The absence of information on this situation in the literature is discussed and work on related topics reviewed.

Laboratory experiments were designed to reproduce the plant conditions in which the corrosion was measured in exposure tests by observing the change in weight of metal specimens. A comparison of the effects of additions to a gas stream was made using several forms of mild steel and different gas stream compositions over a range of temperatures. The results are compared graphically and visual observations are recorded.

The scales produced by the mild steel-sulphur dioxide reaction were analysed by X-ray and chemical methods, and the scale structure determined by micrographic examination.

Some theories on the reaction mechanisms of similar processes, such as oxidation and sulphiding, are presented and the sulphur dioxide attack discussed in the light of them. Suggestions are made with regard to the nature of the attack and some ideas for future work put forward.

The Operating Characteristics of Stedman Gauze Column Packing

by Peter Walmsley (Ph.D., Manchester University)

The hold-up and pressure drop characteristics of a 6 in. diameter column packed with 8.5ft of Stedman packing were investigated. The fractionation efficiency of the packing was also studied with a dilute heavy water/light water system and chlorobenzene/ethylbenzene systems. Experiments were conducted at atmospheric and reduced pressures.

The pressure drop results were correlated empirically and the hold-up results were correlated empirically and by the method of OTAKE and OKADA.

It was found that the fractionation results with the hydrocarbon system could not be correlated theoretically, but an empirical correlation was applied. Anomalous and irreproducible results were found with the water system. An investigation showed that the explanation lay in the poor wetting properties of water on stainless-steel gauze and that if a wettable gauze was used the results were comparable to those found with hydrocarbons.

The Mass and Momentum Transfer Characteristics of Flow Through Column Packings

by Bernard Atkinson (Ph.D., Manchester University)

The main part of this thesis describes work carried out in an investigation of the possibilities of the Carman correlation for the generalised prediction of pressure losses in packings under two-phase flow conditions.

The rapid increase in pressure losses with gas velocity above the "load" point has been investigated and it is suggested that this is probably due to increases in the gas phase density as a result of liquid entrainment in the gas phase.

The use of the Carman correlation to analyse various pressure drop data has indicated that one of the factors previously neglected and which exerts a considerable effect on pressure losses is the angle of gas flow through a packing. It was further found that both particle shape and liquid hold-up exerted a considerable influence on this variable. In view of this, modified equations for pressure drop prediction have been proposed, the selection of the optimum being dependent upon packing shape and liquid rate.

The changes in gas phase density required to wholly predict the increased pressure losses in the loading region have been predicted and correlated.

A model of a single pore has been used in much of the work and is proposed as a laboratory tool for mass transfer work.

An attempt has been made using this model to devise a method for estimating effective wetted areas in random packed columns.

The Behaviour of Sprayed Aluminium Zinc and Magnesium Coatings in the Protection of Mild Steel

by E. L. Smith (Ph.D., Manchester University)

A survey of the literature emphasises the need for further investigation into the corrosion of sprayed aluminium, zinc and magnesium coatings and their protection of mild steel, particularly under immersed conditions.

Potential and pH measurements in N/1000 sodium chloride solutions show that sprayed aluminium, zinc and magnesium foils are anodic to mild steel often for a considerable time, and coupled experiments confirm that good cathodic protection is given to mild steel by these sprayed metals.

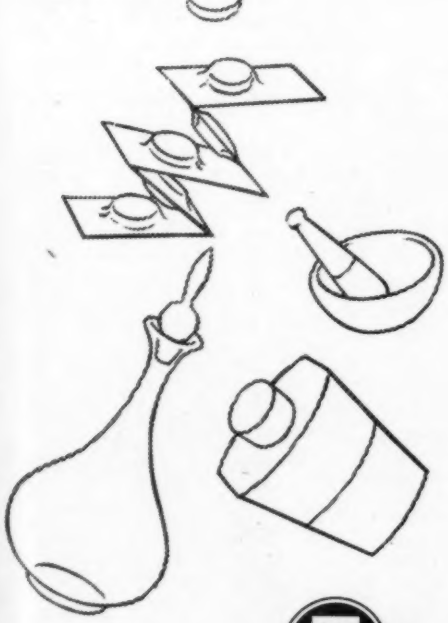
Potential measurements with mild steel panels sprayed to various thicknesses with aluminium, zinc and magnesium indicate that protection is merely physical when the coat thickness exceeds 6 mil. Below this thickness, reactions within pores leading down to the steel become increasingly important. With a coat of 0.5 mil, protection of the steel is only effective for about a fortnight.

Potential measurements and visual observations show that aluminium, zinc and magnesium in the sprayed form are more reactive initially than in the massive state. The reasons for this behaviour are examined in some detail in the case of aluminium, and it is concluded that porosity and internal stress in the sprayed deposit are mainly responsible for the reactivity.

* Valuable information may be lying fallow in many cases in theses presented for higher degrees in universities and not published in journals. *British Chemical Engineering* is therefore arranging to publish a number of synopses of such theses, for the information of our readers, as an occasional feature.

DRY HYGROSCOPICS

Model CO Dehumidifier installation at Reckitt & Sons Limited, Hull, for their Steradent process room.



Many chemicals and pharmaceutical products are harmed by atmospheric moisture. Damp weather may spoil both the product and the smooth flow of the production processes if atmospheric humidity throughout the plant is not controlled. Birlec Direct Dehumidifiers offer a simple and highly efficient means of holding the relative humidity of a process room or storage enclosure at a safe low level.

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PLANT EQUIPMENT NEWS

Miniature Instruments

Taylor Controls have introduced recently a number of pneumatically-operated miniature instruments.

The first of these (the 110K) is an indicating instrument in which the value of a measured variable is shown by means of a roller blind which moves behind a 4-in. vertical scale. This instrument may be fitted with either a pneumatic or an electric alarm. A useful feature, from the instrument panel angle, is that two such indicators can be mounted in the panel space provided by the standard recorder cut-out.

The second instrument (the 111K) will transmit a manually set signal between 3 and 15 psig. A dual 4-in. scale is again provided, one side being for the measured variable and the other for the pressure.

The third instrument (the 112K) is a direct set alarm, which receives signals in the range 3-15 psig. It can be fitted with either a pneumatic or an electric alarm, and at a pre-set input pressure it will give either no output or full output, and vice versa. **Taylor Controls Ltd., 75 Hale End Road, Walthamstow, E.17.**

BCE 8609 for further information

Automatic Oscillator

The designers of machinery and equipment requiring a reciprocating component will find a recent hydraulic device of interest, a typical application being for "doctor" blades.

The device consists of a double-acting cylinder with a stroke of from ½-2 in. in increments of ½ in. Reciprocation is achieved by means of a built-in pilot-operated directional valve which supplies pressurised oil alternatively to each side of the piston. The speed of the stroke can be varied from 6-60 strokes per minute.

The speed of reciprocation can be made independent of load changes by the fitting of a small control valve. The maximum force available in either direction is 1 ton. **Hydraulic Machinery Drives Ltd., 101 London Road, Reading, Berks.**

BCE 8610 for further information

Sub-sieve Sizer

Kek Ltd., United Kingdom agents for the Fisher sub-sieve sizer, are happy to announce further facilities resulting from the increase in demand for this instrument. In future, it will not be necessary for purchasers to arrange shipment direct from the United States; stocks of the Fisher sub-sieve sizer, and spares also, will be available in Manchester. **Kek Ltd., Palmerston Street, Manchester, 12.**

BCE 8611 for further information

Heavy-duty Toggle Clamp

A heavy-duty toggle clamp, originally produced to facilitate the manipulation of plastic materials for which clamping pressures of up to 1 ton are necessary in vacuum forming, has been recently marketed. The exceptional clamping power, together with the rugged construction, make the new clamp ideal for general machining, welding and brazing, bonding and laminating, assembly and so on.

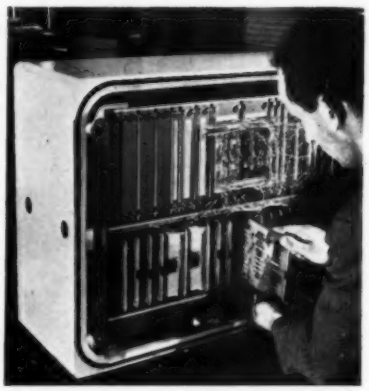
Overall dimensions are 21¼ in. long by 12¼ in. high. Weight is 26 lb, and the angle movement 90°. **F. Brauer Ltd., Grove Road, Harpenden, Herts.**

BCE 8612 for further information

Process Control Computer

The control of manufacturing processes of the kind encountered in the petroleum and chemical field can be effected by a new and inexpensive analogue computer. The computer stores the formula for operating a plant as a mathematic model comprised of a number of equations representing various aspects of the process.

In this computer, known as the "Anatrol", the process variables are represented by dc voltages and these are manipulated by the computer to an overall average computing accuracy of ±1% of full scale, a value which compares with that of many standard instruments and controllers used in process plants. Therefore, the computer does not operate at an unnecessarily high level of accuracy and this, coupled with the fact that the computer accepts input signals and transmits control signals in analogue form, which match the signals sent out and received by the plant instruments, makes the use of analogue/digital and digital/analogue convertors unnecessary. The result is a computer very much less expensive than the simplest digital machine and its low cost of approximately £3000 makes it an attractive proposition. It can receive up to 42 input signals from the



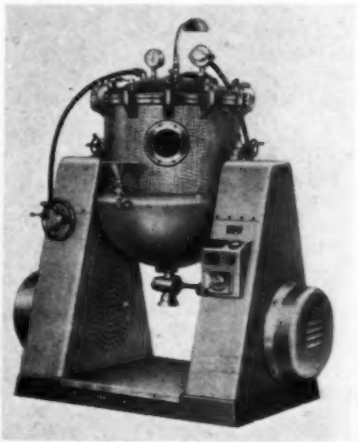
plant and can transmit 6 output signals and, if necessary, more than one computer can be used with each in communication with the other to form a single large unit.

A self-checking facility is built into the computer to ensure its safe use for on-line control. An alarm is given should errors occur in excess of ±1% and the computer can be isolated from the process, if required, with the controls left at the last correct calculated values. The mathematical functions which Anatrol can perform are addition and subtraction, multiplication and division, raising to a power, differentiation and integration. Additional units, however, can supply other functions. **De Havilland Propellers Ltd., Hatfield Aerodrome, Hatfield, Herts.**

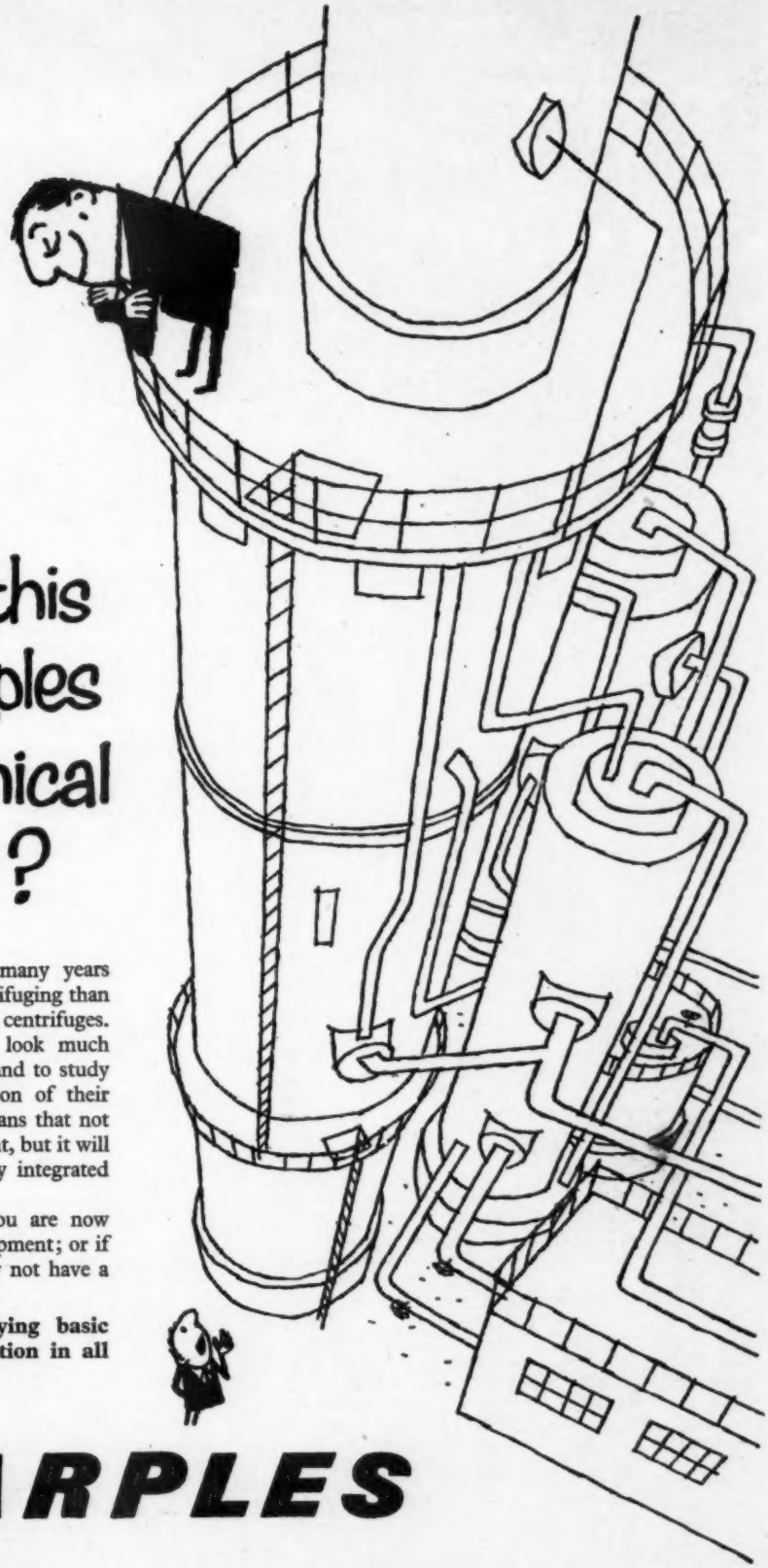
BCE 8613 for further information

Vacuum Mixer

A mixer, especially suitable for the mixing of very stiff pastes and the incorporation of solids in liquids, under exceptionally clean conditions, is now available in the U.K. The machine can be supplied in four sizes in the capacity range 60 to 1200 litres, and with motor horsepower



BCE 8567 for further information



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PLANT EQUIPMENT NEWS

of from ¼ to 6. The vessel has a horizontal shaft for the agitator blades and 18/8 stainless steel is used throughout in the construction. The charge is fitted by connecting the evacuated vessel to the feed material source and heating may be either by electricity, steam or other heat-transfer media. The shape of the agitating blades provides kneading in both vertical and horizontal planes.

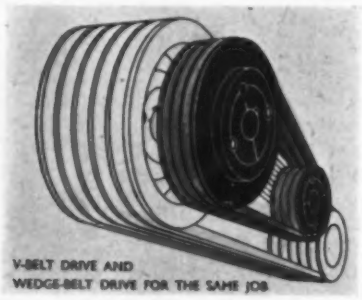
The machines, manufactured by Messrs. V. Tonazzi & C. of Italy, are now obtainable from their agents in this country. **D.C. and Young (Engineers) Ltd. 6 Argall Avenue, Leyton, London, E.10.**

BCE 8614 for further information

Compact Wedge-belt Drive

A notable advance in power transmission by belt drive is signalised by the introduction of a series of units capable of covering every transmission requirement up to 200 hp. In this range the belt length and pulley diameters have been selected, using international standardisation principles, to provide all the usual transmission requirements.

These new units, known as the "Space-savers", apart from the advantages implied by the name, reduce the weight of installations by as much as from 35% to 45% with savings in cost approaching 30%. The accompanying diagram gives an indication of the saving in space.



V-BELT DRIVE AND WEDGE-BELT DRIVE FOR THE SAME JOB

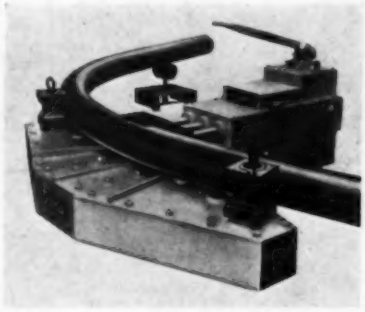
The makers, J. H. Fenner & Co. Ltd., provide drive tables for prospective users of these drives in their recently issued catalogue (reference 135/20/56). **J. H. Fenner & Co. Ltd., Hull.**

BCE 8615 for further information

Heavy-duty Tube Benders

Recently introduced equipment for the pipework fabricator makes possible the bending of heavy-duty 6-in. n.b. pipe of the kind widely used in the chemical and petroleum industries. Two types of tube bender are available, one being provided with three hydraulically-operated rams. This unit is for the heavy-duty bending. In addition, where large quantities of tubing up to 3 in. n.b. have to be bent, a motorised machine can be offered.

Improved features are the type of frame, which allows the bending operation to be carried out in full view of the operator, and the double-acting rams,



which allow full power return and easy removal of the bent tubing from the formers. **Tubela Engineering Co. Ltd., Fowler Road, Hainault, Ilford, Essex.**

BCE 8616 for further information

Report on Thermoelectric Flame-failure Device

Latest in the series of Gas Council reports on equipment (No. 727/60) is one on the Danfoss G.S.20 thermoelectric flame-failure device—a model which has been on the market for some eighteen months. The operating principle is that an electro-magnetic valve is held open by the current resulting from an electromotive force produced by a thermocouple situated in a pilot flame. The device comprises three sections—a manual reset button, a main valve body and a magnet housing.

The pilot gas connection is drilled in a cast projection on one side of the main body, parallel to the valve spindle. A thermocouple passes through two holes in a burner bracket and is clamped by a 6 B.A. roundhead screw. The thermocouple connection to the valve is spring-loaded, a spring being interposed between the flared end of the outer lead and the union nut.

Operation of the push button places the armature in contact with the poles of the electromagnet, seals the gas way to the main burner and opens the main valve to allow gas to pass to the pilot. When the pilot flame is established, the thermocouple is heated and generates an electric potential which provides the current used to energise the electromagnet. When the push button is released after a short period, the armature is held and the valve remains open against the action of a spring.

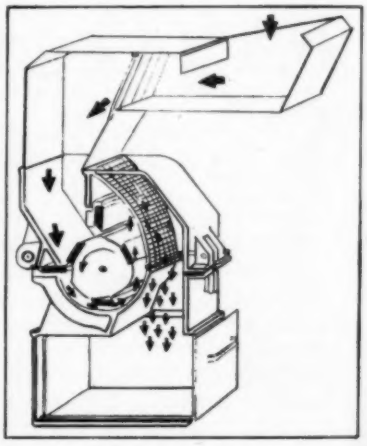
When the pilot flame is extinguished, the thermocouple cools down, the electromagnet becomes de-energised and the armature breaks contact with the poles of the electromagnet; thus the main valve shuts off the supply of gas to both the main and pilot burners. As part of the test, the times for opening and closing were determined with the pilot pressure set at 2.5 in. w.g. and allowing the pilot to burn in free air. An average of six readings showed that time to open was 9 sec., time to close 23 sec.

Despite some criticisms of detail—which are being considered by the manufacturers—the test laboratory concluded that the device, if fitted correctly, satisfies sections a, b, c, d and e of I.G.D.C. Report No. 611/56, U 96 "Flame Protection Practice (1956)" under the heading 1.3 Indispensable Characteristics. **Danfoss Manufacturing Co., 13 Queensway, London, W.2.**

BCE 8617 for further information

Cutting Mill for Plastics

Through a novel arrangement of the screen a new cutter mill introduced by Dreher provides uniform particle size reduction and with the generation of the minimum heat. This machine is widely used for providing the feed for injection moulding machines and for extruders, and is suitable for a range of grinding duties, partly through the use of a massive cutter rotor which is constructed from special abrasion-resisting steel. The rotor has a large swinging moment with adjustable blade cutting angle. Features of the machine are the tangential position of the screen in relation to the rotor and the ready access for cleaning. Special attention has been paid to the shape of the feed hopper, with the result that this machine can reduce in size materials which normally require much larger equipment.



Rotor speed is 1430 rpm; three rotary blades are provided and two stationary blades. Motor horse-power is two and output of plastic materials is in the range of 20 to 40 kg/h.

To change the sieve is a rapid operation not requiring the use of tools; the cutter rotor is attached direct to the driving shaft, which itself is provided with generous self-aligning bearings. **Heinrich Dreher Maschinenbau, Aachen, W. Germany.**

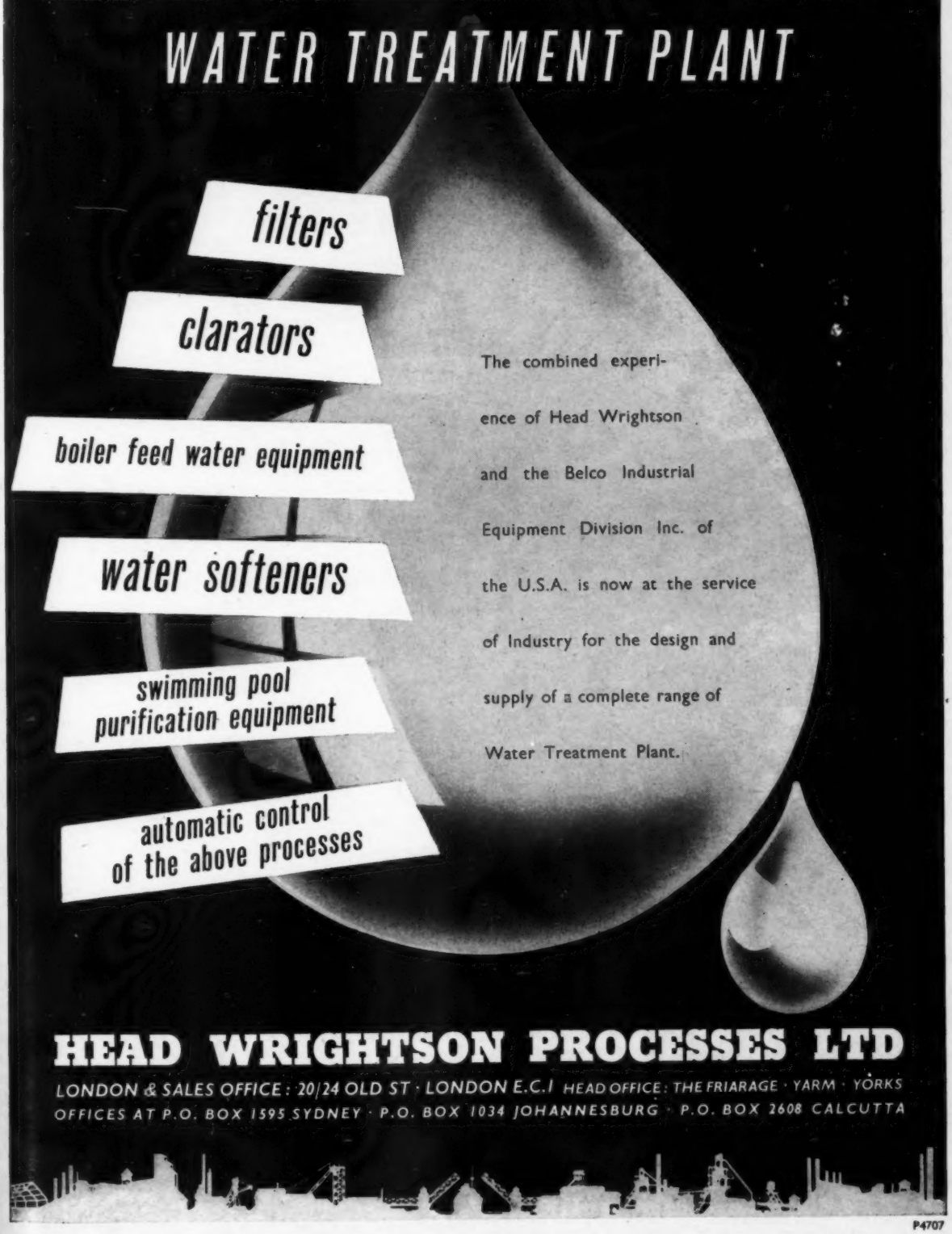
BCE 8618 for further information

Three-speed Gearbox Units

Opperman Gears Ltd. report that they have designed a number of three-speed gearbox units in conjunction with I.C.I. Ltd. The units deliver 25 hp at top speed, but have a starting torque equivalent to five times greater than this figure.

HEAD WRIGHTSON – BELCO

WATER TREATMENT PLANT



The combined experience of Head Wrightson and the Belco Industrial Equipment Division Inc. of the U.S.A. is now at the service of Industry for the design and supply of a complete range of Water Treatment Plant.

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PLANT EQUIPMENT NEWS

The speeds available are 100, 60 and 30 rpm, the motive power being provided by a motor running at 1000 rpm. Gear selection is made by a manual gear shift acting in a gate fitted to the side of the unit.

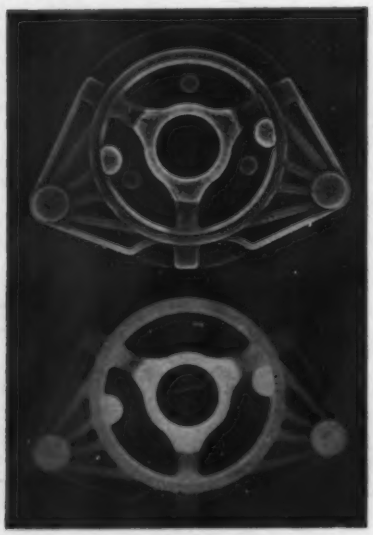
These units are destined for plants in the United Kingdom, South America and South Africa, where they will be driving autoclave mixing mechanisms continuously throughout the day, and the design provides for ten years' continuous service without major overhaul. For this reason particular attention has been given to the lubrication system which consists of a filtered oil supply fed to the various bearings by an electrically driven pump, change speed gears and clutches. **Opperman Gears Ltd., Newbury, Berkshire.**

BCE 8619 for further information

X-Ray Pictures Developed in 15 Sec.

An industrial X-ray picture can be developed in 15 sec with equipment manufactured by Rank-XeroX Ltd., now commercially available in Britain for the first time.

The process—known as xeroradiography—harnesses the speed and low cost of xerography (dry, electrical photography) to X-ray work. No darkroom or wet chemicals are used and, in many cases, xeroradiography clearly reveals the faults which are difficult to detect by conventional X-ray methods.



It has a wide range of applications including the inspection of light alloy castings, hidden structures, assemblies, potted circuits and welds.

A unique feature of xeroradiography is that the image contrast is accentuated at sharp boundaries and for small details such as cracks, pinholes, etc. The overall contrast is, however, low and a large thickness range can be accommodated in one exposure. This feature can lead to considerable economy in the number of radiographs necessary for a given examination. Another attractive feature is that any number of photographic prints, of any convenient size, can be produced containing all the details of the original image.

The resolution of the plates compares favourably with medium-speed non-screen industrial X-ray film and requires about the same exposure. Conventional X-ray apparatus is used. The first photo shows the sharpness of the image produced and suggests the ease with which it can be interpreted. The second photo shows an ordinary radiograph of the same subject for comparison. The xeroradiograph suffers less loss of detail in the photographic process than does a conventional radiograph. The cost of making X-ray pictures by this method is considerably less than that of normal radiography. **Watson & Sons (Electro-Medical) Ltd., Industrial Division, East Lane, North Wembley, Middlesex.**

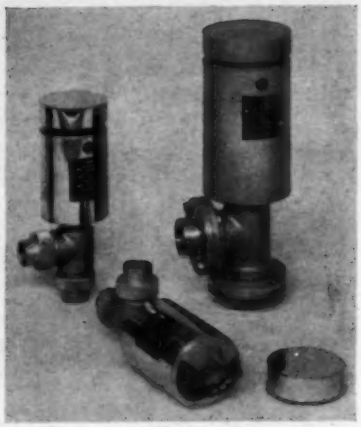
BCE 8620 for further information

High Vacuum Magnetic Valves

A new improved range of magnetic valves for high vacuum use offers a wide range of optional features to suit the growing need for automatic control of vacuum apparatus. Sealing is between a Nygon (vacuum rubber) pad and a brass or stainless-steel cone seating. The valves are designed to operate against 15 psi pressure difference across the seating. In some circumstances, and to special order, this can be considerably improved upon. Time of opening is dependent upon conditions, but generally is ½-1 sec. Spring-assisted closing gives operating times less than 1 sec. The valves can be supplied with either integral contact cooled rectifiers (as illustrated) ready for connection to 200-250 V a.c. supply or for d.c. operation between 160 and 180 V. Other voltage coils can be supplied to order.

The standard ½-in. and 1-in. types may be mounted either vertically or inverted. Larger types may be supplied either for vertical or for inverted mounting. Horizontal operation can be arranged for any size of valve.

Changeover, make or break contacts which operate when the valve is energised may be fitted in order to operate interlocking circuits. The action of these contacts is controlled magnetically, but due to the design of the magnetic circuit the contacts may also be considered as mechanically interlocked with the valve mechanism.

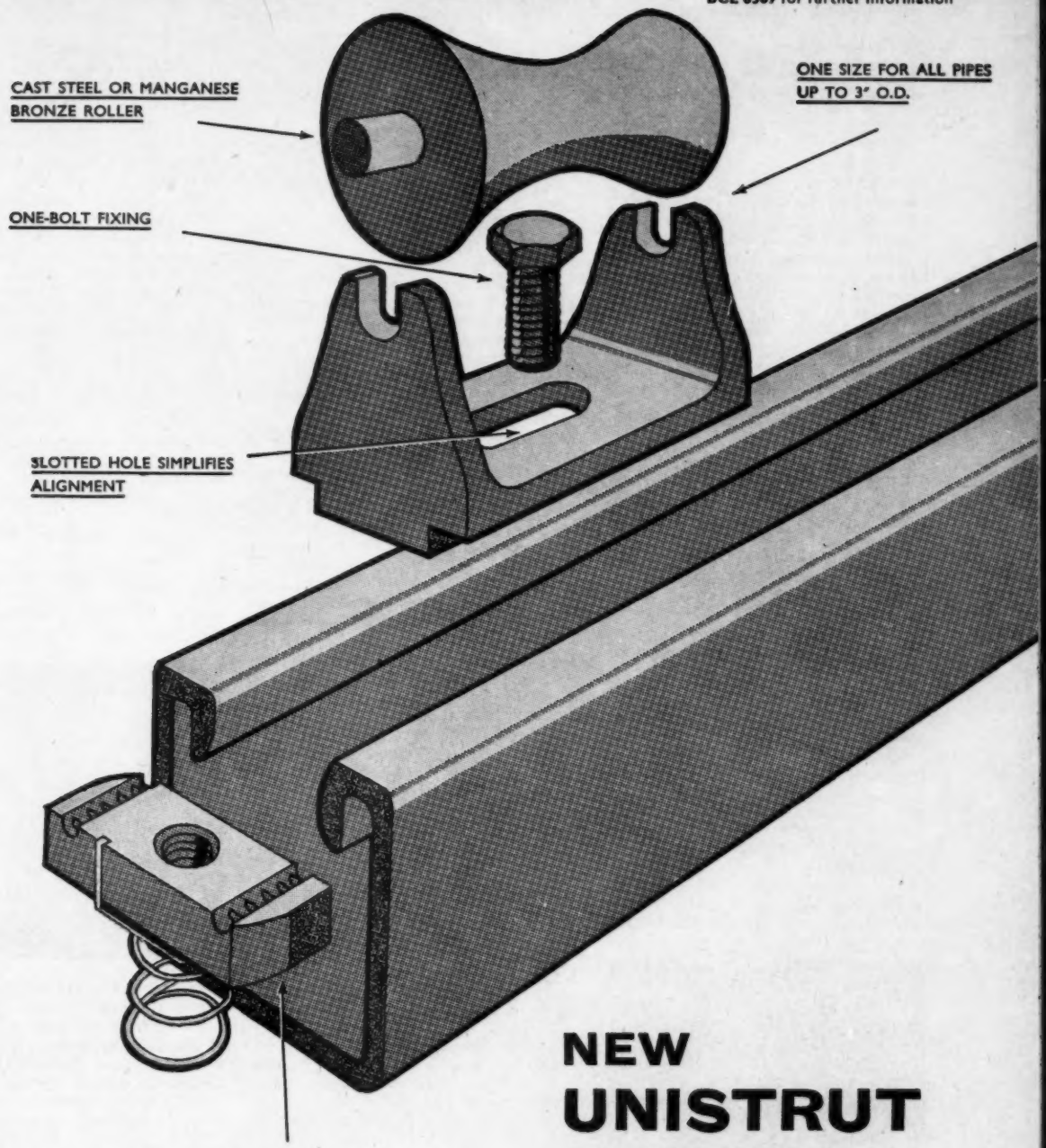


Standard valves are constructed from brass and mild steel, all internal surfaces of the valve body being nickel plated. Pipe adaptors and seating for the standard valves are in plain brass. Alternatively, the valves may be supplied with all parts of the body exposed to the vacuum, plated by the Kanigen process and with stainless-steel adaptors and seating. This treatment renders the valves particularly useful on mercury-contaminated systems. Sizes available for connection to ¼, ⅜, ½, 1, 1½, 2, 3 and 4-in. nominal bore tubing. **N.G.N. Electrical Ltd., Avenue Parade, Accrington, Lancs.**

BCE 8621 for further information

Mobile Crane

A new mobile crane will ultimately replace the original "Staffa Three" and "Staffa Four" cranes. The new "Staffa" crane with its hydraulic luffing gear is able to luff under load and is also now fitted with a double-acting ram to speed up this operation. While following in general appearance the familiar lines of its predecessors, the new crane is of more robust construction, with increased visibility from the driving position pro-


CAST STEEL OR MANGANESE BRONZE ROLLER
ONE SIZE FOR ALL PIPES UP TO 3" O.D.
ONE-BOLT FIXING
SLOTTED HOLE SIMPLIFIES ALIGNMENT
UNISTRUT SELF-LOCATING NUT

NEW UNISTRUT ONE-BOLT PIPE ROLLER

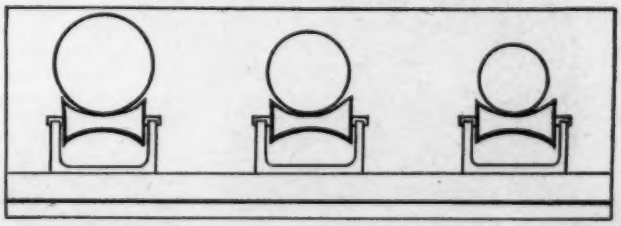
Small pipe installation is now even faster and cheaper with the Unistrut system. This new roller is particularly easy to attach to the Unistrut support framing and also facilitates alignment of the runs.

A single bolt and self-locating nut fixes the chair to the open side of a Unistrut channel, in which it is located by projecting lugs. The roller rests on the chair and is designed to allow free movement of the pipe.

Roller and chair are normally of cast steel; a manganese bronze roller is supplied for use with copper pipe.

*JI 713

INSTALLATION ECONOMY FOR PIPES UP TO 3" O.D.



For drawing of the new component to bring your Parts catalogue up to date, or general information on the Unistrut system, please write to

UNISTRUT DIVISION OF SANKEY-SHELDON LIMITED

43-45 Broadwater Road, Welwyn Garden City, Herts. Tel: Welwyn Garden City 6321 (4 lines)

PLANT EQUIPMENT NEWS

vided by the new open-type A-frame. To ensure that the crane will operate under the most arduous conditions, a heavy-duty hoist box has been incorporated together with a new heavy-duty differential and a cast-steel axle casing. Smooth operation is ensured by the provision of hydraulic brakes. The power unit is a Ford Dexta three-cylinder water-cooled diesel engine developing 27 bhp at 1500 rpm (B.S.S. 1 hr rating) with electric self-starting. The fuel tank has a capacity of 9 gal and fuel consumption is about 2 gal for an average eight-hour working day. With standard jib the maximum capacity is 4 tons at 3 ft clear outreach, and 1½ tons at 10 ft clear outreach. All loads can be lifted free on wheels and capacities are based upon the safe working load, being a minimum of 66 per cent of the tipping load. **Chamberlain Plant Ltd., Buckingham Palace Road, London, S.W.1.**

BCE 8622 for further information

Titanium in Plate Heat Exchangers

The use of titanium for the plates of plate heat exchangers is extending the use of this efficient and compact type of heat exchanger to highly corrosive liquids. An instance is the A.P.V. Paraflow of the bracket-mounted HXC type at the Murgatroyd Salt & Chemical Co. Ltd., Sandbach, Cheshire. It is used for cooling sodium hypochlorite liquor containing 14/15 per cent of available chlorine by the circulation of 22 per cent calcium chloride—both exceptionally corrosive liquids. The heat exchanger has shown no deterioration after several months' run.

A.P.V. Co. Ltd., Manor Royal, Crawley, Sussex.

BCE 8623 for further information

Performance Test of Low-pressure Safety Cut-off Valves

A report has been issued of tests carried out by the Gas Council on Jeavons Type J.54 press-button weep low-pressure safety cut-off valves (Industrial Pattern). The valves tested were the 1-in., 1¼-in. and 2-in. B.S.P. sizes. The valve body and seat, which are integral, are made from cast aluminium alloy, sizes ¾ in. and 1 in. being diecast. The cover is secured by a number of size O B.A. cheese-headed cadmium-plated steel screws which pass through clearance holes in the top cover and body rims to engage with nuts located in recesses on the underside of the body; the diaphragm is held between the screws. A cork washer forms the top seal of the press-button weep assembly and the diaphragm bonding rings are compressed simultaneously. The centre of the cover is tapped to receive a clamping screw which, together with a steel packing piece, holds the valve bob on its seating to avoid damage during transit. A label is attached to the clamping screw, giving instructions for removal of this packing piece. The direction of flow is clearly indicated by the word INLET embossed on the casting. The method of operation is that, on failure of the gas supply, the valve bob drops on to its seating. When the gas supply is restored, the bob will not be lifted off its seating until the inlet pressure, which acts on the underside of the valve bob only, reaches the value shown in Table 1.

Table 1

Size of valve, in. B.S.P.	Inlet pressure which the valve bob will withstand in. w.g.
1	17
1¼	17
2	19

No gas can pass to the appliance burners until all cocks are virtually closed and the weep reset button is depressed, enabling pressure to be built up under the diaphragm and lift the valve off its seating.

The testing laboratory made the following comments: (1) The mild steel screw which passes through the valve bob to engage a nut beyond the diaphragm, thus clamping the two components together, is not protected against corrosion. (2) Each of the valves tested was found to have a cut-off pressure slightly in excess of 1 in. w.g. The figure specified in I.G.D.C. Report No. 676/58, U 9, is 1 in. w.g. (3) With regard to the 2-in. model, it is felt that the recesses at the underside of the valve body which house the eight size O B.A. nuts should either be large enough to accept a box spanner or be sufficiently small to prevent the nut revolving. (4) In the case of the 2-in. size, the weep rate at 2.5 in. w.g. pressure differential was 0.9 ft³/h. This should not be less than 1 ft³/h. (5) The re-opening time when the 2-in. model is connected to the equivalent of 100 ft of pipe is too slow, but modifications suggested in (2) and (4) above should correct this.

These points were discussed with the makers, who have given assurances that the screw referred to in (1) will be cadmium plated; the cut-off pressures will not exceed 1 in. w.g. in bulk supplies; the recesses referred to in (3) will be adjusted to accept a box spanner; and that the weep rate at 2.5 in. w.g. differential in future models will be not less than 1 ft³/h.

The final conclusion was therefore that these valves satisfy the requirements listed in I.G.D.C. Report 676/58, U 9, *Ancillary Equipment for the Operation and Control of Gas-heated Plant—A Review of the Present Position (1958)* (Report No. 726/60 of the Industrial Gas Development Committee of the Gas Council). **Jeavons Engineering Co., Tipton, Staffordshire.**

BCE 8624 for further information

New Centrifugal Pumps

A completely new range of single-stage centrifugal pumps known as the Alcon Thames range are now available, replacing the Alcon self-priming centrifugal pumps. They are available in sizes

from 1 in. to 5 in. The maximum pumping temperature using water (S.G. = 1) is 225°F and the allowable suction pressure 30 psi. Full details and data sheets are available from **Arthur Lyon & Co. (Engineers) Ltd., 6 Carlos Place, Grosvenor Square, London, W.1.**

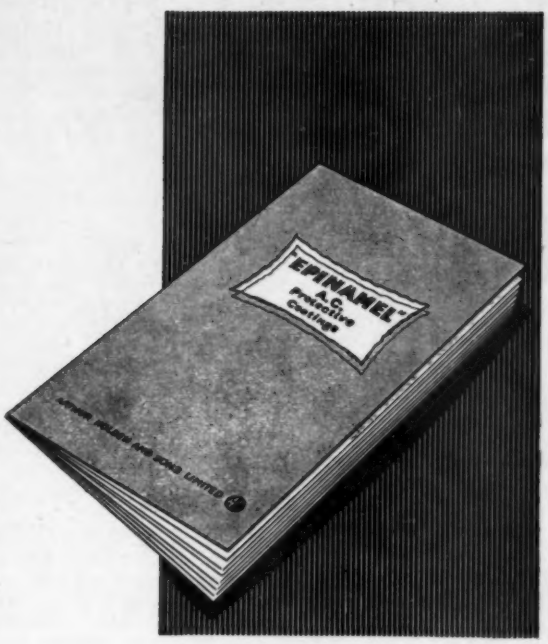
BCE 8625 for further information

High-temperature Torch

The plasma-jet—a new high-temperature torch—was shown for the first time at this year's Farnborough Show. It is particularly suitable for applying coatings of high melting point or reactive material by spraying. Examples are zirconia, alumina and titania; refractory and reactive materials including tungsten, tantalum and silicon; chemically-resistant materials such as titanium and stainless steel; and wear-resisting materials like tungsten-carbide and nickel-chromium-boron alloys. Possible uses include coating of steel parts with chemically-resistant materials such as titanium and stainless steel and the application of hard wear-resistant coatings. **British Oxygen Co. Ltd., Bridgewater House, St. James's, London, S.W.1.**

BCE 8626 for further information

BCE 8570 for further information



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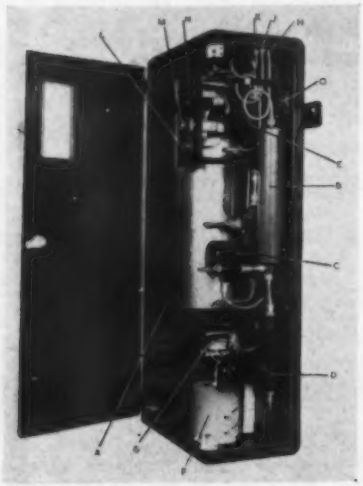
BCE 8571 for further information

PLANT EQUIPMENT NEWS

Combined Purifier/Drier for Hydrogen

A new catalytic purifier for removing oxygen from hydrogen has been built up into a combined unit incorporating an automatic dryer. This unit, having a maximum capacity of 100 scfh, will purify normal commercial grade hydrogen to give a gas with an oxygen content of less than 1 part per million. By the use of a Linde molecular sieve as the drying agent, it achieves a dew point as low as minus 100°F. Maximum operating pressure is 5 psig, the pressure drop at 100 cfh being 1 psig approximately. At 200-250 volts A.C. the power required is 200 watts during reactivation. The drying unit is reactivated automatically in about 5 hr.



A, Drying unit; B, Deoxo catalyst chamber; C, Upper three-way solenoid valve; D, Lower three-way solenoid valve; E, Two-way solenoid valve; F, Converter; G, Transformer; H, Gas inlet; J, Gas outlet; K, Standby gas inlet; L, Reactivation switch; M, Pilot light; N, Reactivation cycle timer; O, Power connection.

The manufacturers state that the platinum metals catalyst used to remove oxygen requires no reactivation, and unless poisoned by sulphur compounds, carbon monoxide, chlorine, and some organic compounds—which are rarely found in commercial hydrogen—should last indefinitely. The unit known as the Puridryer may also be used with other gases such as nitrogen, argon, neon and saturated hydrocarbons, provided that two volumes of hydrogen are present in the gas to react with each volume of oxygen impurity to be removed. **Engelhard Industries Ltd., Baker Platinum Division, High Holborn, London, W.C.1.**

BCE 8627 for further information

Packaged Effluent Instrumentation

Complete instrumentation is now available for automatic correction of effluent pH values and automatic control for detoxication of trade wastes containing cyanides and chromates. For many applications the equipment can be supplied completely installed and pre-wired in floor-mounting cubicles ready for immediate installation. Packaged units can be supplied for flow rates up to 2000 gal/hr and systems are available for large flow rates, together with instruments for batch or continuous treatment plants. **A. M. Lock & Co. Ltd., Oldham, Lancs.**

BCE 8628 for further information

New Publications

Two leaflets published recently by Powell Duffryn Engineering Co. Ltd. describe the range of storage tanks made by the company. Leaflet No. 100 gives details of Cambrian mild-steel cylindrical and rectangular tanks with capacities of from 500 to 12,000 gallons. Prices are quoted for the complete range of tanks and fittings such as pipes, valves, B.S.P. sockets, draw-off taps, as well as for calibration. General information is also given about delivery, fabricating tanks from special materials to customer's requirements, fittings, site erections and pipework. Bulk storage tanks are the subject of Leaflet 101 and pictures of a number of installations in the course of erection are shown. The work of Pipeweld Ltd., an associate company of Powell Duffryn, is also described. This company has established a first-class reputation for its work in fabricating, installing and erecting pipework in oil refineries and chemical, gas, and general engineering plants. **Powell Duffryn Engineering Co. Ltd., Cambrian Works, Maindy, Cardiff.**

BCE 8629 for further information

A new reference booklet (60/1) published by Flexible Drives (Gilmans) Ltd. gives very full details of Skatoskalo machines and their accessories. This equipment is suitable for scaling almost every tubular or drum installation as well as ships' decks, hulls, bunkers, etc. Light, standard and heavy-duty sets are illustrated and described in detail, as well as the various types of petrol-driven and air motor-driven sets.

A comprehensive list of spares, all of which are illustrated in detail, is given in the booklet, along with reference numbers and, in many cases, dimensions.

The many different types of scaling head are also illustrated and described. Some of the many applications of the equipment are illustrated on the insides of the covers. **Flexible Drives (Gilmans) Ltd., Skatoscalo Works, Millers Row, Warwick.**

BCE 8630 for further information

Some of the many industrial drying problems which can be overcome by the use of Humidryer equipment, made by Burnett & Lewis Ltd., are described in publication No. 4/3M. Humidryer equipment removes moisture from gases and liquids by means of activated alumina or silica gel. The brochure describes the many industries in which the equipment is in use, including the chemical and atomic energy fields. Humidryers have been exported to more than 23 countries and the range includes units from laboratory size to plants handling flows of 10,000 scfm for pressures from atmospheric up to 12,000 psig. The units will give from 5-40% R.H. at temperatures down to −100°C.

Another field in which the equipment is widely used is that of air conditioning. It can maintain moisture-free conditions in small sealed-off areas, such as are necessary in the manufacture of electronic components, antibiotics, etc., at a comparatively low cost. **Burnett & Lewis Ltd., Redhouse Industries Estate, Aldridge, Walsall, Staffs.**

BCE 8631 for further information

The BP Research Centre is concerned with problems of discovery and exploitation of sources of crude oil, and also with the transportation, refining and utilisation of crude oil and all petroleum products. The Centre is made up of a number of technical divisions whose work is described in a booklet, "Research at Sunbury". **British Petroleum Co. Ltd., Sunbury-on-Thames, Middlesex.**

BCE 8632 for further information

Origins and manufacture of calcium chloride are clearly set out in a new booklet with tables of properties, uses, precautions in handling, stocking, details of qualities and packages. Finally there are tables of technical data on the salt and solution, including a nomograph for calculating heat transfer and graphs of electrical conductivity. **Chlorure de Calcium, Solvay & Cie, rue du Prince Albert, Brussels, 5, Belgium.**

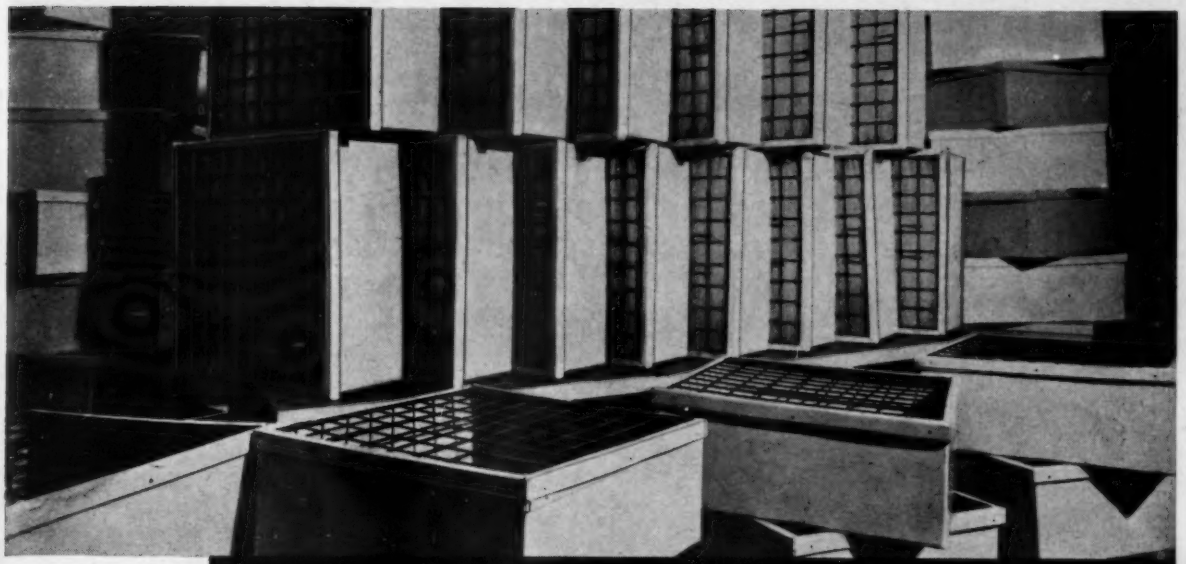
BCE 8633 for further information

A recent pamphlet on chlorinated solvents reviews the manufacture of the four chlorinated derivatives of methane together with trichlorethylene, perchlorethylene and lists their properties. Illustrations are given of uses in dealing with silicones, butyl rubber, cellulose triacetate, aerosols, degreasing, dry cleaning, extraction of animal fats and vegetable oils. Final chapters deal with hygiene, security and transport and there are extensive tables of technical data. **Solvants Chlorés, Solvay & Cie, 33 rue du Prince Albert, Brussels, 5, Belgium.**

BCE 8634 for further information

In a new comprehensive 16-page brochure on chemical demulsifiers for petroleum producers, various application methods of Tret-O-Lite chemical demulsifiers are described. Photographs, photomicrographs and charts illustrate applications, types of emulsions and demulsifiers. The booklet includes a schematic drawing depicting how more than thirty factors in a normal production system may affect treating efficiency and treating costs. **Petrolite Ltd., Savile Row, London, W.1.**

BCE 8635 for further information



Man Mil Plastics Ltd., Stalybridge make washing cells from 'Darvic' p.v.c. sheet to perform the washing and humidifying of air in the Manwood Miller patented capillary washer. (above) They also make water eliminator plates from 'Darvic' p.v.c. sheet for air washers in ventilating equipment. (below)

'Darvic' won't corrode—no wonder Man Mil Plastics Limited make so much use of it

Man Mil Plastics Limited, Stalybridge, make water eliminator plates for air washers in ventilating equipment from 'Darvic' p.v.c. sheet. They also use 'Darvic' to make washing cells which wash and humidify air in the Manwood Miller patented capillary washer.

A great feature of this outstanding material is its superior resistance to corrosion. It is also much lighter than conventional materials and has higher impact strength. 'Darvic' is easy to shape, rigid even in thin sheets and has dimensional stability in atmospheres of varying humidity. 'Darvic' is available in a wide range of colours.

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ICI

World of Chemical Engineering

Polythene Foam Plant

The Dow Chemical Co. of the U.S.A. are to construct a 61,000 sq ft new extension to their Ohio factory to produce "Ethafoam",* a polyethylene expanded plastic. The new plant, due for completion in June 1961, will be adjacent to the present facilities that produce "Styron" and "Styrofoam". Uses for this new expanded plastic will include safety swimming belts, surf-boards, boat fenders, dock bumpers and marine buoyancy applications. New applications are also developing in the fields of package cushioning, construction and thermal insulation. The foam is flexible and of closed cell structure about 30 times lighter than water.

* Registered trade-mark of the Dow Chemical Co.

New Butyl Rubber Plant

The manufacture of butyl rubber is to be undertaken at the Esso Refinery, Fawley, and a 3000-t.p.a. plant is to be erected at a cost of approximately £4½ million. It is estimated that two to three years will elapse before the plant comes on stream. It is intended to supply the entire United Kingdom market and leave, at the same time, a margin for export.

First Coal Tar Udex Unit in Japan Completed at Kokan Plant

The first Udex unit in Japan to separate benzene, toluene and xylene from coke oven light oil has been completed at the Kokan Chemical Industries Co. Ltd. plant here, the plant having been designed by Universal Oil Products, of Illinois.

Benezene from the 500 barrel-per-stream-day UOP Udex unit will be charged to a UOP catalytic condensation unit for the production of ethylbenzene. Soon to be built are dehydrogenation and styrene purification units to convert the ethylbenzene to styrene. Universal Oil Products Co. are also designing the catalytic condensation unit and the styrene facilities.

UOP are also involved indirectly in an extension at the refinery at Abadan in Iran. In this case the Iranian Oil Refining Co. N.V. have awarded a contract to Flour-Schuytvlot N.V., Haarlem, The Netherlands, for the complete design, engineering and construction of a 200-b.p.d. UOP Unifiner-Platformer. The contract is to be carried out by Fluor Engineering & Construction Co., London.

More Boric Acid

Borax Francais S.A., a subsidiary of Borax Holdings, is to double the output of boric acid at its Couderkerque factory near Dunkirk. The expenditure on the project will exceed £100,000. The demands for boric acid are continually increasing, and present trends indicate that the rate of growth will become even greater, particularly in the United Kingdom and countries of the European Common Market.

I.C.I.'s Salt Division to Merge with Alkali Division

For administrative reasons, the Salt Division of Imperial Chemical Industries Ltd. will be merged into the Alkali Division on January 1, 1961. The general policy regarding production and sales of salt will remain unchanged. Relations with suppliers and customers will continue as at present.

The Salt Division has three works producing white salt: at Winsford in Cheshire, at Weston Point situated on the Manchester Ship Canal, and at Stoke Works, near Droitwich. At all these works white salt is produced exclusively by the multiple-effect vacuum process, the Salt Division having abandoned the older open-pan process which was much less efficient, particularly in terms of fuel and labour required. At Weston Point it is possible to load the salt directly into ocean-going ships. For inland distribution the Division has pioneered the development of special vehicles for the transport of dried salt in bulk, designed to pump the salt by air pressure direct into customers' storage without any need for bagging and handling.

The Salt Division also operates, at Winsford, the only rock salt mine in Britain. A major scheme of extension and development of the mine, designed to more than double its capacity, is now nearing completion.

The Salt Division's research work has since the war produced two novel and useful grades: "Dendritic" and "Granular", each the product of a special process. Granular salt is a large-grained product with specialised uses. Dendritic salt, which has an entirely different crystal form from the cubic form of normal salt, is much less dense and has the special property of dissolving easily and quickly and of absorbing moisture.

Company's New Name

Head Wrightson Stockton Ltd. is the new name of the Head Wrightson Stockton Forge Co. Ltd. This change was considered expedient because of the greater diversification of the company's activities. The company was formed over 60 years ago and since then has extended its operations into new industries. Today they design and manufacture specialist equipment for the mining, iron and steel, chemical and allied industries, and the company's services in the constructional field are used extensively overseas.

British Heat Exchangers for Russian Chemical Plant

A large chemical processing plant contract awarded to a West German firm for completion in Russia is to use British plate heat exchangers. The A.P.V. Co. Ltd. is to supply twenty Paraflow stainless-steel plate heat exchangers to the West German firm. Sixteen will be of the large C.H.F. type and four of the I.H.M.B. type. The number of plates in each exchanger varies according to the load. The application of the exchangers has not yet been disclosed.

Production of Polyvinylidene Chloride Co-polymers

The Plastics Division of Imperial Chemical Industries Ltd. is installing a plant to manufacture polyvinylidene chloride co-polymers, and expects the first members of a range of products to be available in production quantities early in 1961. There is a considerable demand in the U.K. for these resins in solvent solution and as aqueous dispersions for coating purposes. They have a high degree of impermeability to moisture, grease, odours and gases and can provide heat-sealing properties. They will be of great value in those trades where paper, cellulosic and thermoplastic films are used for packaging. In the past the U.K. demand has been met almost entirely by imports.

More Pyrethrum for Japan

Japan is manufacturing more insecticides and this is expected to result in greater imports of pyrethrum from Kenya, the world's main source of supply. Because of its quick killing action, pyrethrum is used in many manufactured insecticides and because it is harmless to human beings it is also used alone in many cases.

The increase in production of insecticides is to meet the growing requirements in Japan, traditionally a pyrethrum producer, of public health authorities and also the growing demand in the Far East and South-east Asia. Japanese manufacturers are, of course, well placed to take

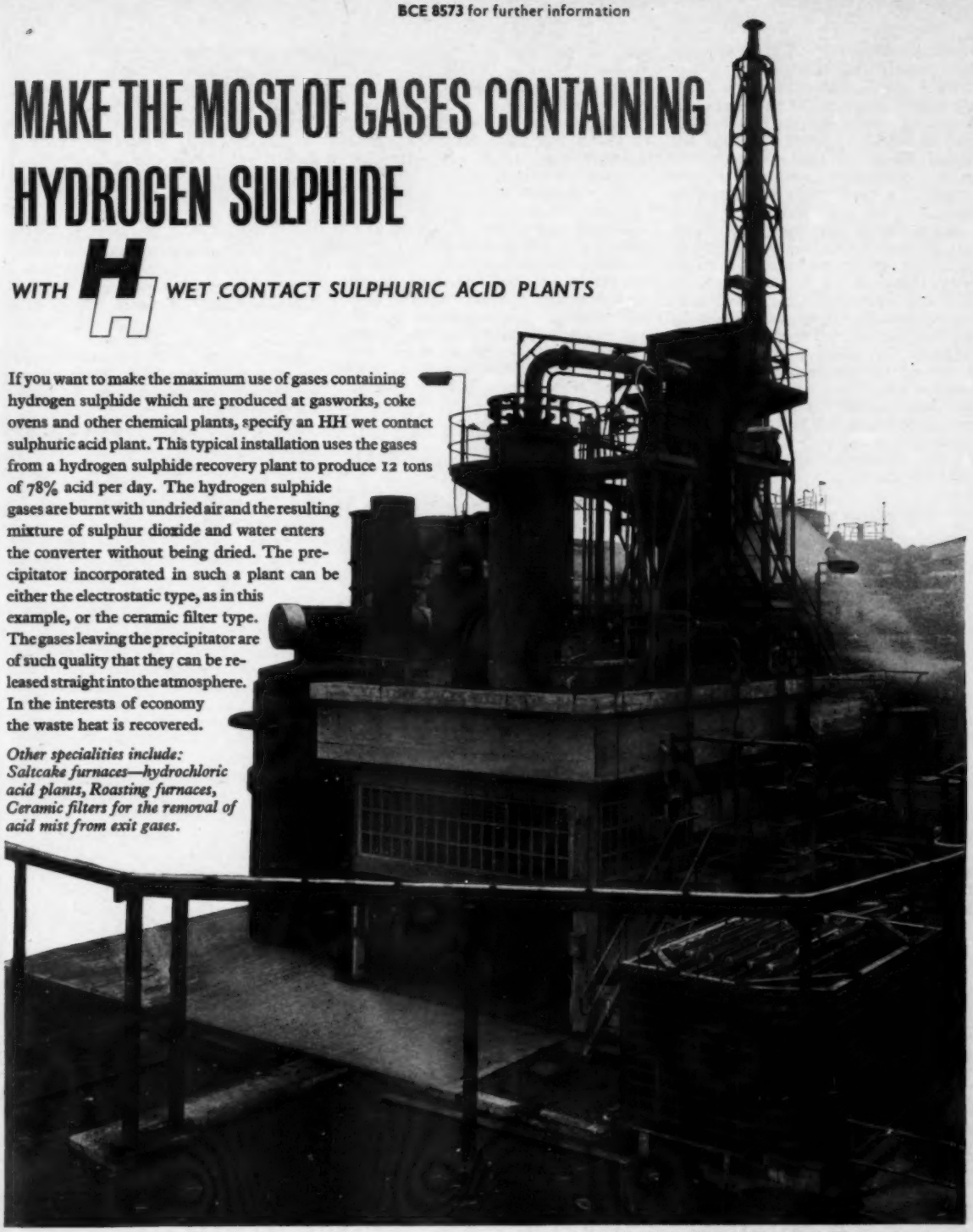
BCE 8573 for further information

MAKE THE MOST OF GASES CONTAINING HYDROGEN SULPHIDE

WITH HH WET CONTACT SULPHURIC ACID PLANTS

If you want to make the maximum use of gases containing hydrogen sulphide which are produced at gasworks, coke ovens and other chemical plants, specify an HH wet contact sulphuric acid plant. This typical installation uses the gases from a hydrogen sulphide recovery plant to produce 12 tons of 78% acid per day. The hydrogen sulphide gases are burnt with undried air and the resulting mixture of sulphur dioxide and water enters the converter without being dried. The precipitator incorporated in such a plant can be either the electrostatic type, as in this example, or the ceramic filter type. The gases leaving the precipitator are of such quality that they can be released straight into the atmosphere. In the interests of economy the waste heat is recovered.

Other specialities include: Saltcake furnaces—hydrochloric acid plants, Roasting furnaces, Ceramic filters for the removal of acid mist from exit gases.



Photograph by kind permission of The North Thames Gas Board

Wet contact sulphuric acid plants by

Huntington, Heberlein & Co. Ltd

SIMON HOUSE, 28-29 DOVER STREET, LONDON, W.1. Telephone: Hyde Park 8191 Telex: 2-3165 Telegrams: Innovation Wesphone London Telex
COMMONWEALTH REPRESENTATIVES: Simon-Carves (Africa) (Pty) Ltd: Johannesburg Simon-Carves (Australia) Pty Ltd: Botany, N.S.W.
Simon-Carves Ltd: Calcutta Simon-Carves of Canada Ltd: Toronto

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advantage of openings in the South-east Asia market.

There is a particular demand in Japan and nearby countries for mosquito coils. These are spiral coils of combustible material containing pyrethrum, which are lighted and slowly burn, killing or repelling mosquitoes and other flying insects. The manufacture and export of these coils are also increasing.

Before the Second World War Japan was the world's main source of supply of pyrethrum. Dr. E. A. BAUM, a technical representative of the African Pyrethrum Technical Information Centre, on returning to Kenya after an extensive tour in the Far East, has reported that whereas Japan produced 12,800 tons of dried pyrethrum flowers in 1935, it produced only 2500 tons last year. There was little indication that Japan would return to its pre-war pyrethrum production level. This pointed to an increasing market in Japan for African pyrethrum, whether as dried flowers or extract.

A Recent Appointment

Blaw Knox Chemical Engineering Co. Ltd., has announced the appointment of Mr. Maurice W. Vincent, B.Sc., A.R.I.C., as technical sales manager. Mr. Vincent graduated from Bristol University and has had extensive industrial experience, including the supply of plant to the process industries. From 1955 until 1960 he was head of the process laboratories with Sharples Centrifuges Ltd., and, before that, development chemist with Murgatroyd's Salt & Chemical Co. Ltd.

Extension of Hydrogenation Unit

The sole hydrogenation unit in the U.K. operated by Marchon Products Ltd., for producing alcohols in the C8/C18 range, is to be extended. The new capacity, which will become operative before the end of 1960, will increase output by more than 50%.

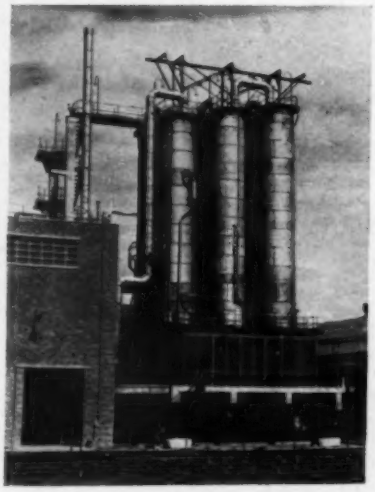
High-level Handling at new Nitric Acid Plant

An interesting handling installation which involves a high-level lifting runway for use at a new nitric acid plant in Scotland has been completed by British Electrical Repairs Ltd.

In the final stages of weak nitric acid production, there are six stainless steel cylindrical absorption towers, the tops of which are approximately 100 ft high. The towers, in three groups of two, are surmounted by platforms at three different levels and each has an opening on top for subsequent coupling to feeder trunking and for the initial purpose of allowing access for the packing of each tower with thousands of ceramic rings, each about the size of a teacup. The rings would require to be raised in bulk up the outside of the towers and lowered in lesser quantities into the towers through the ports.

Loading of the towers manually was considered uneconomic and hazardous and, after consideration of various other methods, a scheme was prepared whereby a 46 ft long runway supported by three goalpost structures was landed on the platforms 100 ft up. As there were three different port-opening positions, the goalpost bases were seated on double channel transverse runners so that, as each group of towers was filled, the whole runway structure could be moved horizontally across to the next set of ports.

The runway structure was erected in two parts at ground level and each part was raised and sited on the platforms by means of a 120-ft-jib mobile crane. A travelling electric hoist unit traversed the runway, raising bulk loads of ceramic rings weighing ¼ ton to platform level, and lowering smaller quantities in "kit-bag" shaped containers into the towers. B.E.R.L. proof load tested the apparatus before it was handed over to the nitric acid plant owners and issued the relevant test certificate.



The special interest in this project does not lie so much in the nature of the crane structure and hoist unit as in the height at which it had to be erected, the fact that the whole structure had to be moved safely across a platform length of 20 ft and the final use to which the unit was put.

Contracts

A PROPOSAL HAS been placed before the Japanese Government by Asahi-Dow Ltd., an associated company of the Dow Chemical Co., for the construction of a polyethylene plant at Kawaski, Japan.

According to the proposal, the new plan would use the high pressure polyethylene process developed by A.G. für Olefinpoly-merisaction (AGFO process).

The principal licensor of the AGFO process, Scientific Design Co. Inc., New York, N.Y., concluded recently a contract authorising Dow's Swiss subsidiary, Dow Chemie A.G., to use the AGFO process for high-pressure polyethylene in several countries on a non-exclusive basis for the benefit of its manufacturing subsidiaries and associated companies. In the case of Japan, however, Scientific Design agreed that the licence be granted exclusively to Asahi-Dow.

Since the proposal also includes the use of Dow techniques in the fields of polyethylene manufacture and fabrication, Asahi-Dow has been able to present a fully integrated proposal to the Japanese Government.

Asahi-Dow manufactures styrene, polystyrene and Saran plastics materials at plants in Kawasaki, Nobeoka and Suzuka City, using Dow processes and technology.

KELLOGG INTERNATIONAL CORP., London, a subsidiary of The M. W. Kellogg Co., New York, has been awarded a contract to engineer and build a new 34,000 barrels/day refinery for Pakistan Refinery Ltd. near Karachi, Pakistan. Participating in Pakistan Refinery Ltd. are the Burmah Oil Co., Caltex, Shell and Stanvac, together with Pakistani interests. Bataafse Internationale Petroleum Maatschappij are the technical co-ordinators for Pakistan Refinery Ltd.

The refinery will consist of a 34,000 barrels/day crude distillation unit, a catalytic reforming unit and a hydrotreater. Offsites include a marine terminal and a crude oil pipeline from the port to the refinery site.

Engineering for the project is now under way at Kellogg International Corp. offices, London. Construction is scheduled to be completed late in 1962.

A CONTRACT FOR a multi-million-dollar ammonia plant which will feature an ammonia synthesis converter with the largest single designed capacity in the world has been awarded Chemical Construction Corp., New York. The plant is being designed and constructed by Chemico for U.S. Phosphoric Products in Tampa, Florida.

The Tampa plant, which will use natural gas as a raw material, will have a capacity of 350 tons per day.

Engineering has already begun on the project, using the Chemico ammonia process in what is essentially a single train of equipment.

The process steps include, in addition to gas reforming, CO_2 removal by a combination of potassium carbamate scrubbing and MEA clean-up.

Methanation will provide final purification prior to the ammonia synthesis operation. In addition, the product ammonia will be stored in an atmospheric storage system. Target date for the completion of the plant is set for late 1961.

SIMON-CARVES LTD. have received from Industrias Quimicas Argentinas Duperial S.A.I.C. (a subsidiary of Imperial Chemical Industries Ltd.) a contract of approximately £250,000 for a sulphuric acid plant at San Lorenzo to produce 207 long tons of acid per day for general sale in the Argentine, where they are the largest suppliers of sulphuric acid. In addition to the conventional acid-producing plant, the contract includes sulphur filtration equipment, a pure acid unit for production of reagent and battery acids, and facilities for production of 65 per cent oleum.

The whole of the material is being supplied from the United Kingdom. Construction on site has already begun, and the plant is expected to go into service about the end of 1961.